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DENSITY AND STRENGTH OF TIES IN INNOVATION NETWORKS: AN ANALYSIS OF MULTI-MEDIA AND BIOTECHNOLOGY

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Density and strength of ties in innovation networks: An analysis of multi-media and biotechnology

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Abstract

In this article we provide an empirical illustration of hypotheses, developed in the literature, on the role of density and strength of ties in innovation networks. We study both exploration and exploitation networks in the Dutch multimedia and pharmaceutical biotechnology industry. We find support for most of our hypotheses but not all. These findings, in line with the mixed results in the literature, seem to indicate that the distinction between exploration versus exploitation, albeit useful, is still too general. There may be a stronger sectoral effect in how exploration and exploitation settle in network structural properties than anticipated thus far.

Key words: innovation, networks, density, strength of ties, governance, biotechnology, multi-media

JEL classification: D23, D83, D85, L14, L63, L65

Introduction

An important issue, in the network literature, is whether in networks for innovation ties should be sparse and weak, to allow for variety, flexibility and low cost of exploration, as claimed in the thesis of the ‘strength of weak ties’. Or alternatively, that ties should be ‘cohesive’, to facilitate trust and collaboration. These questions connect with a debate in the sociological literature on networks where there are opposing views concerning the ‘strength of weak ties’. On the one hand is the view that dense and strong ties (‘cohesion’ or ‘network closure’) allow for social control, and facilitate the build-up of reputation, and social capital, in the form of trust and social norms, which facilitate collaboration (Coleman 1988). On the other hand, Granovetter (1973), in his famous article on ‘the strength of weak ties’, proposed that weak rather than strong ties are appropriate for access to new information. He associated strong (weak) ties with a dense (sparse) structure. In frequent and intense interaction between many actors, in a dense structure, much of the information circulating in the system is redundant. An example Granovetter used was the discovery of new employment opportunities, through acquaintances with which one has only sporadic contacts. Burt (1992) made a clearer conceptual separation between the strength and the density of ties. It is important to acknowledge this, since it is conceivable that sparse ties may be strong and that dense ties may be weak (Reagans and McEvily, 2003). Indeed, the present article will give illustrations of that. According to the thesis of the strength of weak ties, a dense structure

yields redundancy, when the aim is access to new knowledge. If A is connected to B, and B is connected to C, then A does not need a direct connection to C because he can access information from C through B. The cost of redundancy, in setting up and maintaining ties, increases with the strength of ties. Thus, according to Burt, efficiency can be created in the network by shedding redundant ties and selectively maintaining only a limited set of ties that bridge 'structural holes'. Then, time and energy are saved for developing new contacts to unconnected nodes.
Hansen (1999) made a distinction between acquiring knowledge about and knowledge from others, i.e. between the identification of the location and usefulness of knowledge, and the transfer or sharing of knowledge. He, and earlier Uzzi (1997), argued that strong ties promote the transfer of complex knowledge, while weak ties promote the transfer of simple knowledge.
In this debate, the empirical evidence is mixed. McEvily and Zaheer (1999) found evidence against redundancy in an advice network, for the acquisition of capabilities. Ahuja (2000) found evidence against structural holes, for innovation in collaboration. Walker, Kogut and Shan (1997) found evidence in favour of cohesion, for innovation in biotechnology. In view of these apparently inconsistent findings, subsequent studies have taken a 'contingency' approach (Bae and Gargiulo, 2003), investigating environmental conditions that would favour the one or the other view (Podolny and Baron 1997; Ahula, 2000, 2001; Rowley, Behrens and Krackhardt, 2000; Ahuja, 2000; Podolny 2001; Hagedoorn and Duysters, 2002).

Nooteboom and Gilsing (2004) developed additional hypotheses concerning density and strength of ties for networks for exploration and for exploitation. The aim of this paper is to provide an *empirical illustration* of these hypotheses, through a study of the development of networks in two Dutch knowledge intensive industries. The test is not rigorous in the sense of being quantitative, but gives an account of network development on the basis of a variety of qualitative data. We study two types of networks in the multi-media industry and in biotechnology.
This paper proceeds as follows. First, it summarizes the hypotheses. Second, it briefly sketches our methodology of collecting qualitative empirical evidence that illustrates the claims by Nooteboom and Gilsing (2004). Third, it provides an analysis of the development of different types of innovation networks in the Dutch multimedia industry over the period from the early 1990's towards the early years of the new millennium. Next, over the same period, it studies the development of innovation networks in the Dutch biotechnology industry. Finally, it compares the empirical findings with the hypotheses, on the basis of which we draw a number of conclusions.

1. The perspective and hypotheses

In their analysis of density and strength of ties for networks for exploitation and for exploration, Nooteboom and Gilsing (2004) combined a perspective of 'competence', for the acquisition of capabilities and knowledge, and the construction of new knowledge, with a perspective of 'governance', for the management of 'relational risks' (Williamson 1999). The literature on competence building has neglected the governance of relational risk, and transaction cost theory has neglected issues of learning and innovation. A combination of the two perspectives should yield a more complete understanding of inter-organisational relations. So, there is a need to look at both potential rewards and risks, as is customary practice.
On the governance side, there are risks of dependence and of spillover, i.e. the risk that in cooperation others adopt one's knowledge to compete. For risks of dependence,

notwithstanding justified, fundamental criticism of transaction cost economics (TCE), the notion of hold-up risk as a result of specific investments remains relevant, and indeed gains new relevance in innovation networks. On the competence side, there are implications of radical uncertainty, particularly in exploratory innovation, concerning the location and identity of sources of information, and the relevance, absorbability, quality and reliability of information. These yielded further support for existing arguments, and new arguments, for density and strength of ties. The analysis considered six dimensions of tie strength. The central hypothesis is that, for reasons of both competence and governance, in exploration ties need to be dense and strong in most of the six dimensions, while in exploitation ties need to be more sparse, and strong in other dimensions.

Nooteboom and Gilsing (2004) distinguish between networks for *exploration* and for *exploitation* (March, 1991). Exploitation entails improvements with respect to established practice, while exploration entails the development of new practices. In the literature on innovation networks, the distinction between exploration and exploration was used earlier by Rothermael and Deeds (2004). Exploration and exploitation build on each other: exploration develops into exploitation, and exploration emerges from exploitation, in ways that go beyond the present article. The point here is that networks for exploration and for exploitation may require different structure and strength of ties.
In exploration, there is uncertainty about which technical standards will later yield the 'dominant design', there is much volatility of prototyping, the emphasis in competition lies on technical feasibility and a 'race to the market', there is a great deal of trial and error, and knowledge is often highly tacit. In exploitation, technical development has consolidated in a dominant design, uncertainty in supply and demand has subsided, knowledge becomes more codified and diffused, new players and consumers enter into the emerging market, competition shifts to efficient production and distribution, and the emphasis shifts to a new dominant design in organisation. These differences are summarised in Table 1. Next, Nooteboom and Gilsing (2004) considered dimensions of tie strength. According to Granovetter (1973: 1361), the strength of (personal) ties entails a combination of 'amount of time, emotional intensity, intimacy (mutual confiding) and the reciprocal services' that characterise the tie. In their earlier theoretical analysis Nooteboom and Gilsing (2004) arrived at an adapted and extended set of dimensions of tie strength, based on combined perspective of competence and governance. This is summarized in table 2.

The hypotheses for a network for exploration, proposed by Nooteboom and Gilsing (2004), were as follows:

- Network structure needs to be sufficiently *dense* for three reasons. First, to hedge bets on the future existence and relevance of sources of information. Second, to utilize third parties to aid judgement of the meaning and value of knowledge (triangulation), and to aid in its absorption. Third, to yield reputation mechanisms, needed in view of the limited feasibility of contractual control. Cost of redundant relations is both limited, in view of limited size of relation-specific investments, and of limited relevance, since in exploration competition is less on price than on feasibility and fast prototyping. Structure should not be too *stable*, allowing for sufficient entry and exit, to enable variety of knowledge and flexibility of configuration.
- Ties are weak in *control*, but strong in terms of *scope*, *frequency* of interaction, *trust and mutual openness*, and *investment in mutual understanding.* Trust is needed, next to reputation mechanisms, due to the limited feasibility of contractual control (and lack of hierarchy). Specific investments in mutual understanding require sufficient *duration* to make them feasible and worthwhile. However, duration <u>need</u> not be very

long, since in view of fast knowledge change specific investments in mutual understanding have a short economic life. Duration should not be too long for two reasons. First, it should not inhibit fast architectural innovation, if that is needed, as is often the case in systemic technology. Second, if ties are exclusive, long duration will yield too much identification, killing learning potential. Specific investments are recouped, mostly, on the basis of frequent interaction, which is needed also in view of the large scope of ties, and for building relation-specific trust.

By hypothesis, in a network for exploitation, conditions are more or less the reverse of those that apply to a network for exploration. First Nooteboom and Gilsing (2004) turn to network structure. Dominant designs have emerged, and technological and market uncertainty have decreased. Here, considerations of efficiency are crucial, since competition has shifted to competition on price, with new entrants in the emerging market. Due to increased competition on price, there is a need to utilise economies of scale, and this opportunity arises since due to decreased uncertainty on the part of customers the market has enlarged. As a result, there is increase of scale, a shakeout of producers, and resulting concentration. Contingencies here are entry barriers to the emerging market and the extent of economies of scale. The drive for efficiency requires the elimination of redundant relations. Thus, concerning structure:

- There is a requirement for a less *dense* structure. The increased codification of knowledge furthers diffusion without the need for relation-specific investments of mutual understanding. This enables a less dense structure, since now one can identify what competencies are and will remain relevant, who has those competencies, and who is likely to survive in the industry. Investments shift to large-scale production, distribution systems, and brand name, which are all long-term, and increase in size and economic life. In view of such large and often sunk investments, with a long economic life, and to maintain efficient division of labour, network structure is likely to be *stable*. Under systemic conditions, exploitation may require considerable *centrality*.

Concerning strength of ties:

- *Duration* of ties depends on the *relation-specific investments*, which depend on the flexibility of technology: more generic or flexible technology entails that investments are less relation-specific. In increased division of labour for the sake of efficiency, there is an increase in specialisation that makes that relations entail more specific knowledge on a narrower *scope* of issues. Reduced uncertainty and codified, diffused knowledge on a more narrow range of issues enable the specification of contracts and the monitoring of compliance, entailing a shift from *trust* to *control*. Increased specialisation, reduced scope and reduced need for trust reduce *frequency* of interaction, i.e. interaction in the exchange or joint production of new knowledge (purely in terms of transactions, there may be very frequent ‘just-in-time’ deliveries from suppliers).

These hypotheses are summarised in Table 3. Now we turn to the empirical part of our paper, to explore in how far the hypotheses hold.

(Insert table 3 about here)

2. Methodology

To illustrate the arguments and hypotheses we have four cases. In our study of the development of multi-media we have a case of a network of exploration that developed into a network of exploitation. In our study of biotechnology we have a case of division of labour, with one network, of universities and small biotech companies, conducting exploration and

another network, of small biotech firms and large pharmaceutical firms, carrying new products into exploitation.
Our approach is that of ‘history friendly modeling’ (Malerba et. al. 1999, Malerba & Orsenigo 2002). This entails that theory is formed and tested on the basis of historical reconstructions of specific developments, in industries or technologies. The test is whether the theory can account for the stylised facts of historical development. The theory is to be changed if it cannot explain observed phenomena. In the present paper, historical developments are constructed from data on relevant events, such as the use of technology, emergence of products, development in supply and demand, structures of collaboration, and whatever indications can be found on the strength of ties.
Such data were collected mainly from extensive archival sources, such as scientific literature, reports from consultancies, research bureaus, participant firms, and the Dutch Ministry of Economic Affairs. These archival sources were supplemented with a variety of interviews with firms and individuals that are or were participants in the developments involved. The interviews were unstructured, since they were conducted on different subjects with people in different roles. In this combination of sources, industrial structures and histories were pieced together. Finally, we approached four recognized industry experts to validate our analysis.[1]

3. Networks in the multimedia industry

Over the 1990’s two types of networks emerged in the Dutch multimedia industry. One emerged in the early 1990’s, and peaked around the mid 1990’s, with its main focus on technological exploration (section 3.1). A second network emerged from around 1995, and peaked around the start of the new century. In this pattern the focus was more on exploitation, in a fast development of multimedia products for a growing mass-market. Thus, here we find a case of a network transforming itself from exploration to exploitation (section 3.2).

3.1 Network 1 : Technological exploration

Innovation in the Dutch multimedia industry started to take off after the adoption of Internet as the worldwide standard for on-line communication, around 1990. Before the advent of Internet, the technological knowledge base was scattered over a variety of separate technologies such as information -, communication -, audiovisual- and data-transmission technologies. These technologies were mostly stand-alone, and most exploration was done by large, R&D-intensive firms, each in its own domain (Directie EDI 1996). The arrival of Internet yielded the insight that for its full utilisation a fundamental restructuring of these various technologies was required, in technological convergence. Continuous progress in the field of digitalisation provided a technical opportunity for this. This led to an increasing number of new entrants, from the early 1990’s onwards, who focused on the opportunities offered by technological convergence (Schaffers 1994, Beam-it 1999). These new entrants complemented the search activities of the large, R&D-intensive firms, creating a newly emerging innovation trajectory. A network developed in collaboration between small, specialized multimedia firms and specialized suppliers of hard-& software. Their joint exploration and search activities resulted in an increasingly *systemic* integration of technologies such as information technology, communication technology, screen display

[1] We thank Pim den Hertog and Sven Maltha of Dialogic for their valuable comments on an earlier version of the analysis of networks in the multimedia industry. See for more information on these two experts www.dialogic.nl. Moreover, we thank Christien Enzing and Sander Kern of TNO-STB for their valuable comments on an earlier version of on an earlier version of the analysis of networks in the pharmaceutical biotechnology industry. See for more information on these two experts www.tno.stb.nl. Of course, any remaining error remains entirely our responsibility.

technology and language technology. The development of a multimedia-application required the integration of different technologies for which change in one required adaptations in others (Condrinet 1998, Smeulders 1999). As a result, strong interdependencies developed to effectuate technological integration. Firms needed to cooperate in hard- and software, in joint development, where no single firm had the necessary knowledge of all technologies. This created a complex search-process: when exploring the convergence of different technologies, one had to consider first which technologies had relevance, and next to consider all of these potential relevant technologies simultaneously, due to their interdependence (Schaffers 1994). This search process took place by much trial-and-error, with a great deal of tacit knowledge on which search directions to explore and how to explore them (Peelen e.a. 1998). This inhibited a more structured approach to the search process, making it difficult to create a division of labour. To 'organise', then, for the rapid exchange of this tacit knowledge, informal networks of symmetric relations developed. Coordination of these relations was mainly through a 'free-souls mentality', which entailed a large degree of informality, *openness, trust, lack of formal control,* and lack of concern for spillover risks (Dialogic 1999). This confirms Hypotheses 7 and 8 (Table 3). In this network, it was rational not to be obsessed with appropriability, but rather to stay connected with the exploration activities going on and to 'live and let live' in order to keep up to date with the rapidly changing knowledge base (Peelen e.a. 1998). Empirical evidence of this 'free-souls mentality' was found, for example, in the network of firms that cooperated in the technological exploration of multimedia image processing technology in the period around 1996-1998. When asked what they perceived as the most important benefit of cooperation when exploring this new technology, 60 – 65 % of the firms mentioned access to and exchange of knowledge, and only 5–10 % indicated that they worried about the risk of spillover (Oerlemans and Meeus, 2000). Spillovers within this network were frequent, but were both outgoing and incoming, and not engaging in this flux was not an option. There were ample opportunities for hold-up, but these also did not cause any great concern (Dialogic 1999). This mentality of give and take developed due to the fact that firms needed each other, and there were no alternatives. Then one will simply have to make it work, on the basis of trust. Trust was engendered by mutual respect among professionals struggling with shared problems (Bouwman and Hulsink 2000). An informal safeguard against free-riding and spill-over was that in order to keep up with the rapidly changing knowledge base, all partners had to do their part, in give and take, to keep up with the development of their absorptive capacity, and shared tacit knowledge, to benefit from what partners develop. Also, give and take was supported by a strong reputation mechanism in overlapping communities with frequent contacts (Leisink 1998, Leisink e.a. 2000, Wegberg 1997). To deal with this uncertainty at both the input side (what to use) and the output side (whom to supply to) of the search process required a *dense* network structure (H1) with *low centrality* (H3) and *low stability* (H2), with a large number of new entrants. Ties were of fairly short duration (from a few weeks to a few months) (H5), strong in terms of scope (H4), *frequency* of interaction (H6), and, as already indicated, in mutual *openness* (H8), while low in control (H7).. This combination of dimensions of tie strength created the possibility for an easy recombination of ties so that the systemic knowledge base could be explored rapidly. See also figure 1, which sketches the configuration of this network.

(insert figure 1 about here)

In sum, this network matched the hypotheses for an exploration network under conditions of a systemic knowledge perfectly (Table 3).

3.2 Network 2: Technological exploitation

Increasingly, different elements of the knowledge base in multimedia technology became more codified, for example by means of downloadable software from the Internet (Schaffers e.a. 1996). In combination with a growing market for on-line applications, this led to the development of a second, more incremental, exploitation-oriented innovation trajectory with a dual learning object: the understanding of customer needs as well as keeping up-to-date with the constantly changing technological knowledge as explored in learning regime 1. Empirical evidence of this dual learning was that, according to an extensive survey on multimedia firms by Peelen et.al. (2000), between 65-70 % of all multimedia firms especially invested in a better understanding of customers (through improvements in marketing, communication and customer focus) as well as in knowledge on (adjacent) technologies.
As a result, a second type of network emerged around 1995 that consisted of firms from more traditional industries such as printing, advertising, audio-visual production, IT and pr/advertising. The network structure reflected a growing division of labour: communication with customers was done by a centrally positioned 'main-contractor' with a reliable reputation (*high centrality,* H3), surrounded by a *stable* structure of firms (H2) with specialised competencies for solving various technical issues (Leisink e.a. 1998, 2000, Bakker and Jonkheer 1999, Dialogic 1999). The focus of this network was on quick delivery of standard products such as e-mail and websites, enabled by an increasingly *codified* knowledge base. The dominant mode of organising consisted of a relatively *non-dense* network of ties (H1), mainly between the core firm and the various supplying firms (Leisink 1998, Leisink e.a. 2000). These relations were of *long duration* (approx. 18 – 36 months) (H5),. In contrast with H6 interaction was still frequent (roughly between daily and weekly contacts, through e-mail and face-to-face discussion). This was needed to accommodate the integration and delivery process (Leisink 1998, Leisink e.a. 2000). These relations generally showed *limited scope* (H4) mostly concerning specific, specialised issues, pertaining only to this integration and delivery process (Bouwman and Hulsink 2000). As analysed, these supplying firms only had direct ties among one another when needed in view of the integration process. For appropriation, the network needed to be able to deliver a 'turn-key solution' that required from the involved firms that they could understand one another well and could count on one another (Dialogic 1999, Mijland 2001). In sum, the systemicness of the knowledge base in combination with demand for quick delivery of relatively standard products yielded a relatively non-dense and stable network, with high centrality, with durable ties, and frequent interaction, that integrated all required, complementary skills. See also figure 2, which sketches the configuration of this network.

(insert figure 2 about here)

Governance was based on mutual dependence, reputation built on past performance, and trust in intentions, all supported by the fact that most of the partners came from within a region (Leisink 1998, Leisink e.a. 2000). This is in contrast with hypotheses 7 and 8, which predicted low trust and high formal control for explotation. Spillover risk was governed by mostly *exclusive* relations. Over the 1990's, this system turned out to be self-reinforcing. When relations endured and experience accumulated, firms grew closer in terms of cognition and trust-in-intention and could therefore speed up their single-loop learning. This further enhanced possibilities to appropriate, which reinforced the existing network structure and further deepened the learning regime embedded in this network (Dialogic 1999, 2000).
In sum, this network confirmed most, but not all, of the hypotheses for an exploitation network for systemic technology, specified in Table 3: a non-dense, stable structure, with high

centrality, with ties that were strong in terms of duration and weak in terms of scope. Counter to the hypotheses, however, ties were still strong in frequency, and governance was not based so much on formal control as on mutual dependence, reputation, and high trust and mutual openness, supported by regional embedding. This deviation from hypotheses can be explained by the fact that although the network was oriented towards exploitation, there was still a great deal of incremental innovation, in single-loop learning, to optimise and fine-tune novel configurations of technology and service.
Some players, such as notably publishers, had to make radical changes to their core activities and organisational 'focus'. They were forced to explore, or lose out completely, by the novel context of Internet being forced upon them. They had been (and to some extent still are) holding back, using Internet only for presenting their traditional products in new ways, rather than for configuring novel products, in mixed media, in full utilisation of the opportunities offered by digitilisation. As a result, entrepreneurial spirits within publishing companies, frustrated by this conservatism, spun off their own ventures, thus contributing to the entry of new players in the earlier exploration network.

4. Networks in the biotechnology industry

As noted earlier by Powell et. al. (1996: 117), from the early 1990's towards the early years of the 21st century, there was a revolution in biotechnology, with a scientific base in immunology and molecular biology replacing the older knowledge base in organic chemistry. Corresponding with this, there is a 'new breed' of Dutch biotechnology firms. The number of entrants rose from 4 in 1992 to 10 in 1998, making 50 in total. Most of these Dedicated Biotechnology Firms (DBF's) saw R&D as their core activity and they specialised, through contract research, in general platform technologies with a potential of wide variety of applications in the pharmaceutical industry as well as in non-pharmaceutical applications such as agriculture and food. There were many technological spillovers by means of licences to different parts of the biotechnology sector both inside the Netherlands and internationally. Especially platform-technologies generated such spillovers in pharmaceutical applications such as e.g. genomics, combinatorial chemistry, high-throughput screening and bio-informatics. These technologies also had a potential for application in a wide variety of non-pharmaceutical applications such as plant breeding, food-processing (e.g. diagnostic kits), speciality chemicals, other applications of bio-informatics, and biological catalysis (Enzing and Kern, 2002). DBF's that specialised in platform technologies generally did not have the ambition to become an independent producer of pharmaceuticals. Rather, they aimed to provide tools and services to pharma firms that were involved in drug discovery and development. The advantage of this dual structure of exploration and exploitation model was its potential for rapid commercialisation with (hopefully) fast cash-flows.
In the course of the 1990's, a 'knowledge-exploration value chain' emerged in the field of general platform technologies in the Netherlands, which can be schematically depicted as indicated in figure 3:

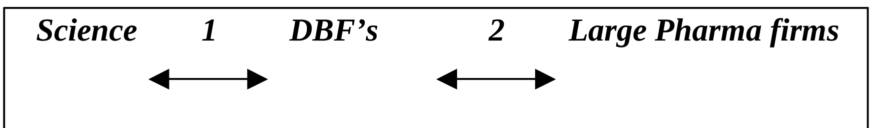

Figure 3 : Emerging knowledge value chain in the field of general platform technologies

Within this value chain we can identify 2 main types of networks:

Network 1 **:** an exploration network of DBF's with academia
Network 2 **:** networks for transfer from exploration to exploitation, each consisting of one or more DBF's with a large pharma firm.

This configuration is very similar to the one identified by Rothermael and Deeds (2004: 202), who found a sequencing of exploration alliances, typically between DBF's and universities, followed by exploitation alliances between DBF's and pharma companies.

Here, DBF's, as intermediaries between exploration and exploitation, performed a key role in commercialising scientific knowledge. They connected a 'basic-science environment', with its emphasis on new knowledge, in exploration, with a 'techno-economic environment' that emphasised economic value (McKelvey, 1997) and carried novelty into exploitation. In this way, DBF's were faced with a dual selection environment, which stressed scientific excellence on the one hand, and economic performance on the other hand. We now analyse both networks in turn.

4.1 Network 1 :Technological exploration

Network 1 was made up of relations between DBF's and (public) research institutes, with a strong focus on exploring new knowledge. The knowledge base on general platform technologies was mainly of a *stand-alone* nature, due to its strong scientific base in molecular biology and genetic engineering (Ministerie EZ 1998). Due to some high quality research at Dutch universities, there were opportunities for Dutch DBF's, although mainly pertaining to some niches (Degenaars and Janszen, 1996). The final outcome of this search process was highly *codified* knowledge (in publications). The underlying search process of scientific discovery was characterized by a lot of trial & error and was highly specific to individual persons and research communities. This process entailed many tacit elements that were difficult to codify, such as the formulation of hypotheses, test set-up, accurate execution, interpretation of test results, reformulation of hypotheses and so on. It was characterized by serial, incremental improvements that led to the accumulation of tacit knowledge within stable research groups of academics and DBF's (Casper, 1999). In this network, a clear spatial concentration could be observed, especially around the universities of Amsterdam, Groningen, Leiden, Utrecht, Nijmegen, Wageningen, Maastricht and Delft (Van Geenhuizen and van der Knaap 1997, van Geenhuizen 1999). The mainly tacit search process entailed that personal contacts, with *high specific investments in mutual understanding* and *frequent interaction* (H6) were necessary to allow for an effective transfer of this tacit knowledge (Allansdottir et.al., 2002). In addition, physical proximity enabled easy access to a talent pool of skilled workers, which enabled knowledge spillovers by the mobility of researchers (van Degenaars and Janszen 1996, Geenhuizen 1999). In addition, opportunities were generally diffuse, which required regular checks and adaptations of the search process into the most promising search direction. The importance of physical proximity was further indicated by the fact that most patents were assigned to inventors from within the Netherlands (Enzing and Kern, 2002). So, we find an network characterised by substantial exploration and searching around a specific area of expertise, resulting in a high level of cumulativeness of tacit and mainly stand-alone knowledge shared throughout a network of academics and biotech-firms. To deal with this complex search process a *dense* (H1) and dispersed (*little centrality*) (H3) network emerged between universities and research institutes on the one hand and DBF's on the other hand (van Geenhuizen and van der Knaap 1997, Enzing 2000). This network was built up relations of fairly *long duration* (lasting years) (in contrast with H5), a *high frequency of interaction,* in *mutual openness* (H8), although limited to a fairly *narrow scope* (in contrast with H4) of mostly scientific issues (Degenaars and janszen 1996, Enzing 2000). Spillovers within this network were frequent, and mutual understanding was fairly specific, creating a risk of hold-up. In contrast with H7, governance was based on a combination of *formal control,* with contracts, supported by monitoring by peer control and review, and on mutual dependence. See also figure 4, which sketches the configuration of this network.

(insert figure 4 about here)

This confirms some but far from all hypotheses for exploration networks. Confirmed are the density and non-centrality of structure, and ties that are strong in terms of frequency of interaction, specific investment in mutual understanding, and mutual openness (H1, 3, 6, 8). In contrast with the hypotheses, however, are the considerable stability of the network, the long duration of ties, narrow scope, and governance by formal control (H2, 4, 5, 7) . While there is much mutual openness, trust is not so clear. How can this be explained?

Narrow scope of ties can be explained by the fact that the knowledge involved was highly stand-alone and specialised, and there was no need to explore also on subjects such as organisation, production, marketing and distribution. One of the theoretical arguments against the use of contracts, in exploration, was based on the assumption that then knowledge is highly tacit which hinders the specification of contracts. Here, we find that in processes of development the skills involved are highly tacit, but the outcomes are highly codified, and those can be, and are, subjected to formal monitoring and control. Concerning the duration of ties, note that the theoretical analysis predicted the need for *sufficient* duration of ties, to make specific investments in mutual understanding worth-while, and here the need for in-depth understanding of highly specialised knowledge required high levels of such investment. Also, in view of the stand-alone technology short ties were not as important, for innovation by reconfiguration of elements in a system, as under the systemic technology of multi-media. However, the duration of ties did seem excessive, for exploration. The theoretical argument against stable structure and ties of long duration, where the thesis of the 'strength of weak ties' comes into its own, was that those would jeopardize the diversity of knowledge needed for radical innovation and the flexibility of configuration needed for Schumpeterian 'novel combinations'. Did limitation manifest itself? In the theoretical discussion it was noted that durable ties would not necessarily lead to inertia, provided that they are not exclusive, and nodes in some way obtain fresh insights from outside sources. This is precisely what showed up in further analysis.

Further analysis showed that the network might be seen as a 'core' network, complemented by a *non-stable* periphery of ties with *short duration*, outside the Netherlands, tapping into state-of-the-art knowledge from foreign universities and firms (Degenaars and Janszen 1996, Enzing and Kern 2002, Enzing e.a. 2003). This was mostly in codified form, such as papers and publications, which were relatively easily accessible from a distance, and could be governed by formal means such as licenses and research contracts. The high rate of change of knowledge made that such distant sources of knowledge succeeded one another on a regular basis, which required the constant monitoring for new potential sources. So, the strength of these ties was *low in duration*, and *low in specific investments*, since requisite absorptive capacity for the distant ties was generated by the stronger ties in the core network. Also, there was only very limited interaction on a *narrow scope* of issues, mainly restricted to the contents of the license (Enzing e.a. 2002). Substantial technological interdependencies were absent so that ties could be replaced without the risk of creating bottlenecks in adjacent technological areas.

In sum, in network 1 a dual network structure emerged, built up of a dense and stable network of local ties strong in frequency, specific investments, duration and control, supplemented with an instable fringe of short ties with no specific investments and little frequency of interaction, which are, at times, strong only in control (in case of contracts or licensing). The core network deals with complexity and the periphery offers variety. In the core, dense, local relations provide stability for the development of an in-depth understanding and triangulation. In the periphery, there are high levels of entry/exit and low tie strength (in all dimensions except, occasionally, formal control).

4.2 Network 2: Technological exploitation

Network 2 was concerned with exploitation, i.e. the development of commercially viable products based on the newly explored knowledge by network 1. Network 2 was made up of relations between DBF's and large pharma firms. The rationale underlying this network was as follows. Large pharma-firms were exploitation oriented, but needed to keep up to date with a rapidly changing knowledge base, with all its diversity, built up from various scientific disciplines (Enzing 2000, Ernst and Young 2000). At the same time, business opportunities pertained to niches and were also difficult to define up-front, making it difficult for pharma firms to decide which fields of knowledge to invest in and which to ignore (Allansdottir e.a. 2002). To deal with the variety of expertise and the diffuseness of opportunities, the pharma firm contracted, in *formal control* (H7), a number of DBF's that offered a variety of specialised expertise. This enabled the pharma firm to explore various opportunities at the same time without the need to make substantial investments and commitments (Ernst and Young 2000).

Since knowledge is highly *stand-alone,* specialised and specific to the DBF's, the network is made up of mainly bilateral relations between large pharma-firms and DBF's, with little interaction among those. In other words, there was *high centrality* of the pharma firm (H3), and *little density* (H1), in a hub-and-spoke structure (Roijakkers 2003). From the viewpoint of a large pharma firm, he was basically subcontracting research to a DBF and his interest lay not in the research process itself, but in the codified knowledge coming out of it, for which he had sufficient absorptive capacity, so that *little specific investment* for understanding was needed, and *frequency of interaction was limited* (between twice a month and twice a year) (H6). Hence, they faced little hold-up risk, and ties did not *need* to be of long duration, at least from the perspective of the pharma firm. In fact, *duration was generally fairly long*: between 2 and 5 years (Enzing 2000, Enzing e.a. 2002) (H5). However, the pharma firm evaluated contracts with DBF's on a regular basis. Depending on the outcome of such an evaluation, the contractual relation was durable up to the point that opportunities proved to be viable. If not, relations terminated and parties separated. In other words, network structure was in fact *fairly stable* (H2). Since the DBF's could not absorb or implement the pharma firm's core activities of lengthy clinical testing, and large-scale production and distribution of end products, risk of spill-over to DBF's was very limited (Roijakkers 2003). Thus, from the perspective of the pharma firm there was no need for exclusive ties. *Openness and trust were very limited* (H8), in view of codified knowledge and *formal control* (H7), and interaction was limited to a *narrow scope* of activities (H4). See also figure 5, which sketches the configuration of this network.

(insert figure 5 about here)

In sum, apart from some ambiguities, this network conformed to the hypotheses for a network of exploitation, with a structure of low density, considerable stability, and high centrality (H1, 2, 3), and ties that are strong in formal control, fairly strong in duration, and weak in scope, frequency, specific investments in mutual understanding, trust and openness (H7, 5, 4, 6, 8). The ambiguities concern the stability of structure and the long duration of ties, while from the

perspective of the pharma firm there was little reason, due to limited specificity of investment and limited systemicness of the technology.
From the perspective of the DBF, however, the situation looks quite different. A DBF seems to have to make fairly specific investments, to understand the needs of the pharma firm, and to know who to deal with, and how, in its large organisation. And how about spill-over risk? Could sensitive information on its knowledge spill over to a competing DBF that is also a spoke of the pharma hub? To what alternative pharma firm does a DBF have access, and what are its switching costs? It seems that while the pharma firm can easily switch between DBF's, the DBF's are more captive. In fact, dependence appears to be rather one-sided, making the DBF vulnerable. Perhaps the stability of the network and the long duration of ties is a concession to the DBF's. However, we are not surprised to see that in this arrangement the profitability of the DBF's is generally low. In this structure they can maintain their profitability only if they can offset their dependence by a unique and scarce competence that is in high demand among several pharma firms. Alternatively, perhaps they should also engage in production of specialties, in niche markets for which dependence on a large pharma firm is less, to widen their options and increase countervailing power.

5. Conclusions and discussion

In an analysis of both competence and governance issues in innovation networks, Nooteboom and Gilsing (2004) argued that in exploration network structure need to be dense and not too stable, and ties need to be strong, or fairly strong, in 4 out of six dimensions of tie strength: scope, frequency, specific investments in understanding, and trust/openness, and weak in the dimensions of duration and formal control. Some of the arguments confirm and elaborate existing arguments:

- Especially in exploration, a reputation mechanism is required, and this requires density (Coleman, 1988)
- Especially in exploration, with problems for formal control, ties must be strong in trust (Coleman 1988), and the transfer of complex knowledge requires strong ties (Uzzi, 1997; Hansen, 1999).

The notion of knowledge complexity, in exploration, was elaborated in terms of wide-ranging uncertainty, a high degree of tacit knowledge, cognitive distance and limited absorptive capacity. As corresponding dimensions of tie strength Nooteboom and Gilsing (2004) proposed scope, which needs to be high due to the wide range of uncertainty, relation-specific investments needed for building mutual understanding and trust, sufficient (but still limited) duration of ties to recoup such investments, and high frequency of interaction, for the same reason and for the building of understanding and trust. In the arguments for density, Nooteboom and Gilsing (2004) added considerations of uncertainty concerning the relevance, the location and the future existence of sources, which requires density 'to hedge relational bets'. Nooteboom and Gilsing (2004) also added uncertainty concerning the quality and reliability of information, requiring triangulation, and the need for redundant ties to pool absorptive capacity, which require density. This points to a new insight on Coleman's closure argument: apparently his considerations not only have relevance from a governance perspective but, in exploration, also from a competence perspective. A dense structure enables to hedge bets concerning what knowledge is relevant, to complement one's absorptive capacity and for triangulation to test validity and relevance of new knowledge and information.
So, it may not yet be possible to identify which ties will be redundant, and redundancy is needed for reasons of uncertainty. The cost argument against dense, redundant ties is of

limited relevance, in exploration, since competition does not focus yet on price, and because the size of (specific) investments in relations is still limited. The density of ties facilitates spillover, but in exploration this risk is limited by a high degree of tacitness, limited absorptive capacity for emerging knowledge, and fast change of knowledge.
In exploitation, by contrast, coordination of division of labour, for the sake of efficiency, may entail centrality, which reduces density, while ties are generally strong only in control and duration, and weak in other dimensions.
The hypotheses developed by Nooteboom and Gilsing (2004) were illustrated by four case studies, in empirical analyses of the Dutch multimedia and pharmaceutical biotechnology industry. The empirical findings on the network in the multimedia industry that focused on technological exploration confirmed our hypotheses. As expected, the network structure is dense and ties are strong in scope, investment in mutual understanding, frequency of interaction, trust/mutual openness, and limited in duration. This enabled a rapid exploration of a systemic knowledge base through a rapid recombination of ties. The second innovation pattern in multimedia of technological exploitation confirmed some of the ideas of a network in exploitation, but not all. As argued, this deviation from hypotheses may be explained by the fact that there was still a great deal of incremental innovation, in single-loop learning. This need to optimise and fine-tune novel configurations of technology and service made that ‘full exploitation’ could not be reached during the period that we studied (2nd half of the 1990’s).
In the pharmaceutical biotechnology industry we identified two innovation patterns. The innovation pattern that engaged in technological search and exploration confirmed the hypothesis of a high network density and high tie strength in terms of frequency of interaction. However, in contrast to the hypotheses were the findings that the strength of ties was high in terms of duration and low in scope. This yielded an interesting lesson. Narrow scope could be understood from the fact that technology was stand-alone and highly specialised, and in its focus on science there was little need to include issues of organisation, production, marketing and distribution. Long duration could still be understood, according to the underlying theory, as resulting from high specific investments in mutual in-depth understanding in a complex field of knowledge. However, according to theory they would jeopardise the variety of knowledge needed for exploration, and the flexibility needed for Schumpeterian novel combinations. Interestingly, further analysis showed that the core network of durable ties was complemented by a peripheral network of more volatile ties, to access outside state-of-the art knowledge. This confirms the idea that long duration may not have negative effects on exploration, provided ties are not exclusive, and the nodes involved tap into outside sources which are more variable, in ties of short duration. The innovation pattern that engaged in exploitation again confirmed all relevant hypotheses.

So, the lessons from this can be summarised as follows:

1. The multimedia case showed that in exploitation frequency of interaction can still be fairly high (H6), and, related to this, governance can still be informal and trust-based to a considerable extent (H8). This can be understood from the fact that considerable adjustment and incremental innovation was still taking place. In other words, between the archetypes of full exploration and full exploitation, there are intermediate situations.
2. While in exploration much knowledge is tacit, as originally assumed, the biotechnology case showed that the knowledge output that is exchanged may be highly codified, as in scientific research. This enables the use of contracts and monitoring for governance, in contrast with hypothesis 7.
3. The biotechnology case showed that in exploration ties of long duration may not only be needed, in view of high and highly specific investment in mutual understanding,

but may also be warranted. In that case though, such durable ties should not be exclusive and the actors involved should also tap into outside sources, through ties that are more variable and of short duration. This qualifies hypothesis 5.

4. Counter to the hypothesis 4, in exploration ties can be weak in scope, particularly in scientific exploration, where knowledge is highly specialized and stand-alone, and issues of organization, production, marketing and distribution are not (yet) relevant.

An important lesson is the following. In exploration, the key task is to create access to cognitive diversity, in view of Schumpeterian novel combinations. Following our empirical analysis, this can be done in two different ways. One is through the 'classical way' according to the 'strength of the weak tie' argument. This is what we found in the peripheral network in network 1 in biotechnology, with its focus on technological exploration of a stand-alone technology. Here we found an important role of ties that were weak in duration, specific investments and scope, and that were non-redundant with the dense core made of DBF's and universities. Another way of creating cognitive diversity is through a dense network in combination with a high volatility (entry/exit) of ties. As analysed, this is more beneficial under conditions of a systemic knowledge as we found in network 1 in multimedia. In this case, density was needed to preserve integrity of the emerging technological architecture while entry/exit created diversity.

Another issue here is why the two exploitation networks differ between biotechnology and multimedia. The explanation of this relates to how exploration and exploitation are separated. Multimedia offered an example of a separation of exploration and exploitation in time, with network structure evolving from the first to the second. Biotechnology offered an example of a separation of exploration and exploitation in place, with exploration in networks of universities and biotech firms, exploitation in pharma firms, and biotech firms in a (not very lucrative) linking position.

The key to understanding this difference in separating exploration and exploitation lies in the nature of the knowledge base that underlies both industries. As our empirical analysis indicated, the knowledge base on multimedia was a highly systemic one (Teece 1986), forming a sort of technology system, built up of different types of technologies such as hardware and software technology. These strong mutual dependencies created complexity in the exploration process as firms needed to consider all relevant technologies simultaneously, with the risk of creating inconsistencies among these systemic technologies. To explore then requires to decouple such technological dependencies by a separation of exploration from exploitation in time. As our analysis of network 2 in multimedia illustrated, such separation then required a transformation process from exploration to exploitation over time. As a consequence, full exploitation in network 2 could not be achieved as long as exploration was going on in network 1.

In contrast to multimedia, the knowledge base on general platform technologies in pharmaceutical biotechnology was more of a stand-alone nature (Teece 1986). Due to its stand-alone nature, new technology would not have highly disruptive consequences for adjacent technologies or other parts of the overall system. Moreover, the codified nature of knowledge, as an outcome of the search process, made that that it could be accessed fairly easy, even at distant locations. This enabled a clear division of labour that separated exploration from exploitation: DBF's specialised in exploration whereas incumbent firms in the pharmaceutical industry specialised in exploitation. In this way full exploitation in network 2 could be combined with exploration going simultaneously in network 1.

Now, all this points to a new insight namely that there is also a sectoral effect at work, in how exploration and exploitation 'settle' in a specific industry. The distinction between exploration versus exploitation, albeit useful, is still too general. There may be a stronger sectoral effect in how exploration and exploitation settle in network structural properties than anticipated in the literature thus far. In this respect, our study indicates some explanations of the ambiguity of empirical results in previous literature, as we discussed in the introduction (McEvily and Zaheer 1999, Ahuja 2000, Rowley e.a. 2000, Hagedoorn and Duysters 2002, Bae and Gargiulo, 2003), by specifying contingencies. Given its important role in learning and innovation processes, the properties of the knowledge base may form such a contingency, such as the distinction between stand-alone (as in the biotechnology case) versus systemic (as in the multi-media case). A more systemic technology requires higher network density than a more stand-alone one. Some forms of knowledge may spill over less easily than others, or change faster than others, and this reduces spillover risk of network density. In exploration, in some cases cognitive distance may be less than in others, lessening the need for specific investments in mutual understanding, as well as the frequency of interaction. Another contingency is the tacitness of knowledge. At first Nooteboom and Gilsing (2004) assumed that in exploration knowledge tends to be more tacit, and that may still be true, but the biotechnology case showed that in exploration outcomes may be more abstract, codified knowledge, which enables more formal governance. Another contingency lies in opportunities for trust, even in exploitation, in spite of opportunities for contracts from more codified knowledge, and lesser frequency and greater anonymity of transactions. As indicated, another contingency may lie in intermediate forms between exploration and exploitation. The analytical framework behind the hypotheses allows us to understand, or even predict, the effects of such contingencies, leading to revised or qualified hypotheses.

The empirical work reported here is informal and case based, with extensive archival analysis, supplemented with a variety of interviews, subjected to triangulation. So, another priority for further research is to conduct more systematic and formal tests. For this one might conduct more formal analysis of network structure, and one would need to complement this with more extensive and systematic measurement of the proposed six dimensions of tie strength. Such data are not readily available in existing sources, and would require extensive and longitudinal data collection, which will be a complex task.

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	Exploration	Exploitation
overall characteristic	volatility	consolidation
type of uncertainty	radical technical and market uncertainty	market risk
focus of activity	prototyping	production/distribution
competition	technical and market viability	price
type of knowledge	more tacit	more codified
diffusion of knowledge	limited	wide

Table 1: features of exploration and exploitation (Nooteboom and Gilsing 2004)

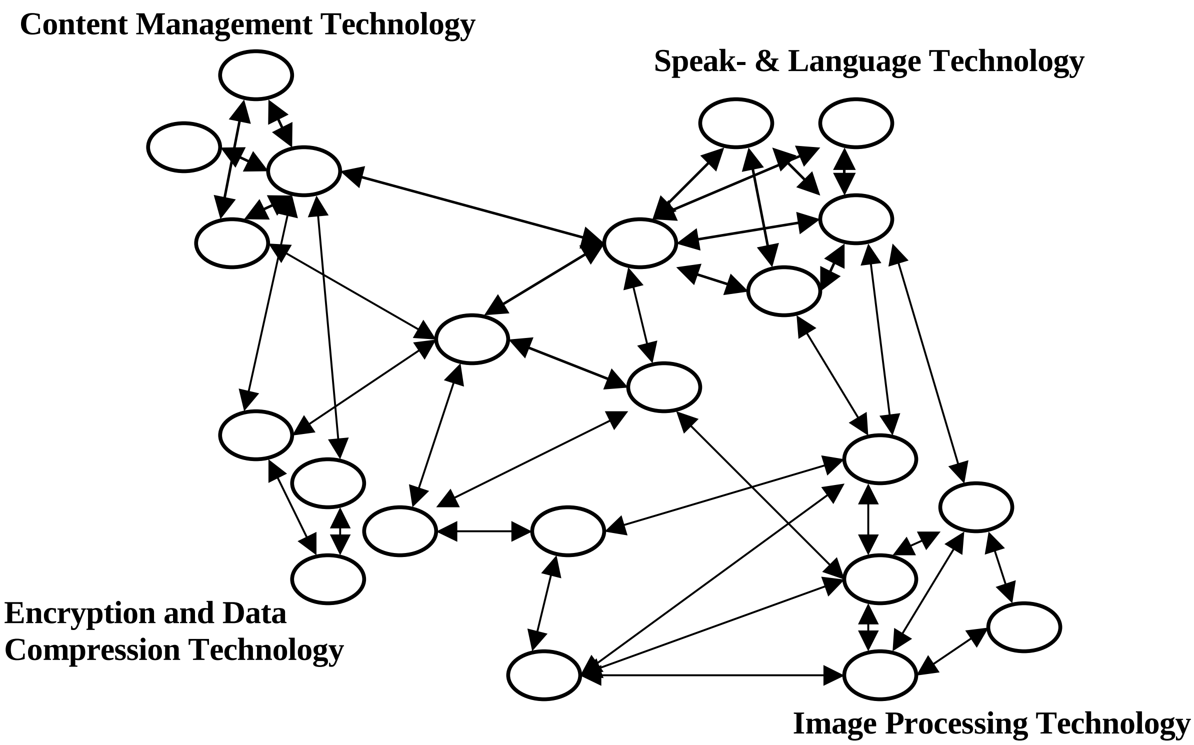
In personal networks (Granovetter)	In innovation networks
reciprocal services	scope specific investment in mutual understanding
amount of time intimacy emotional intensity	duration frequency of interaction trust/mutual openness formal control

Table 2: Dimensions of tie strength (Nooteboom and Gilsing 2004)

hypotheses	network features	exploration	exploitation
	network structure:		
1	density	high	low
2	stability	limited*	high
3	centrality	low	often high
	strength of ties:		
4	scope	wide	narrow
5	duration	limited*	often long
6	frequency of interaction	high	low
7	control	low	high
8	trust/openness	high	generally low

* especially when technology is systemic

Table 3: networks for exploration and exploitation (Nooteboom and Gilsing 2004)



Informal and formal relations, knowledge going two ways

Figure 1 : Systematic representation of the exploration network in multimedia

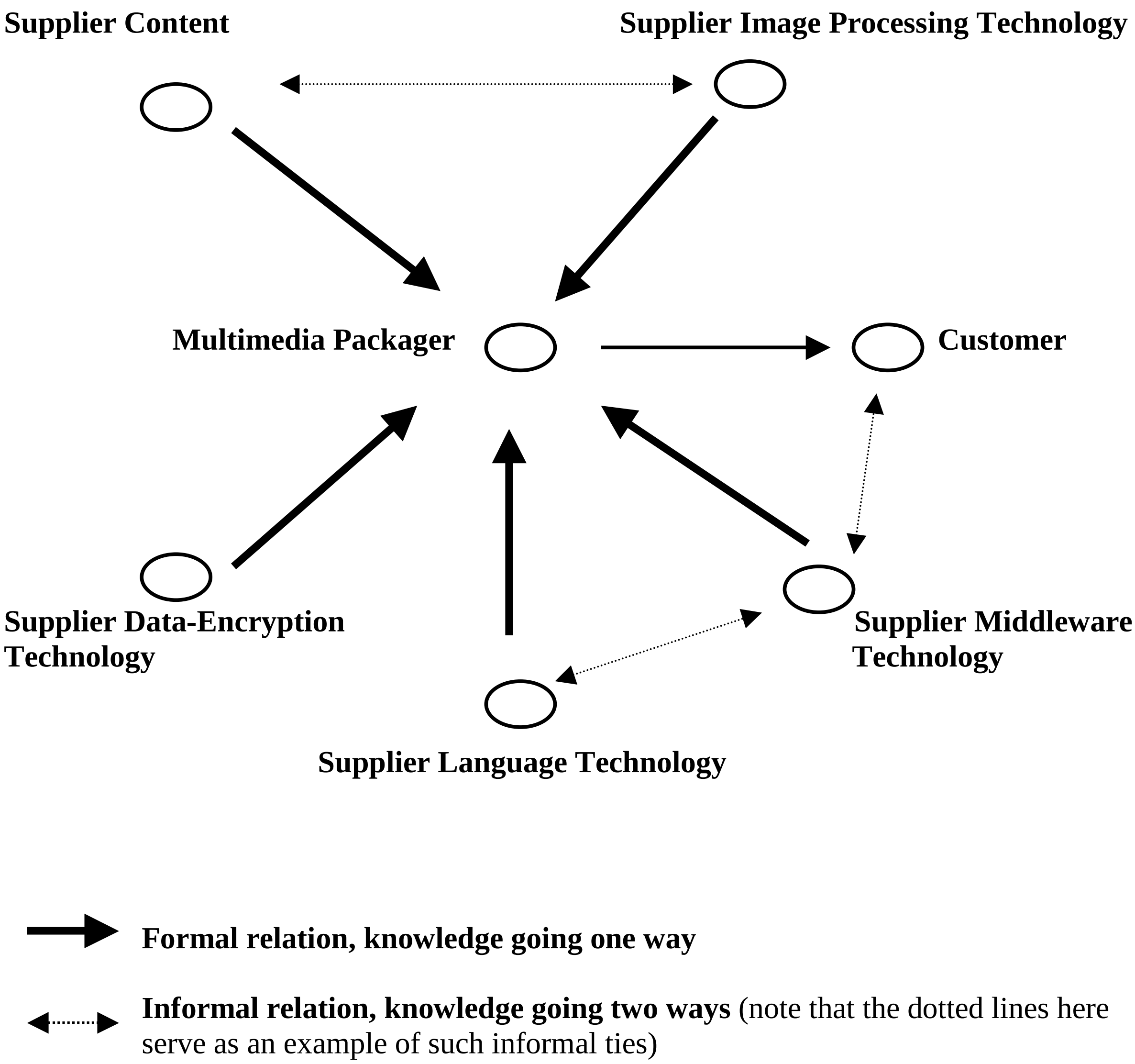
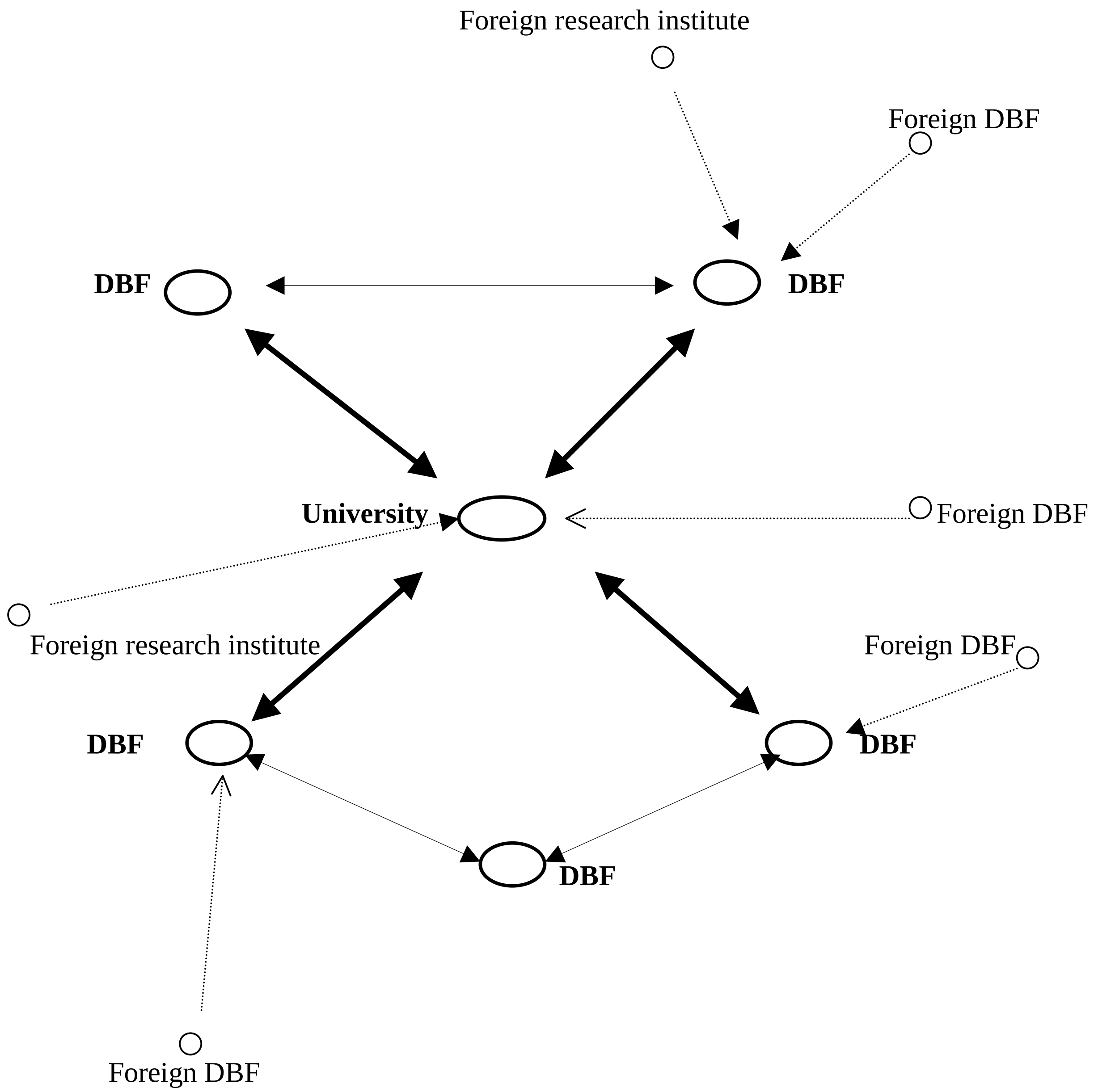


Figure 2 : Systematic representation of the exploitation network in multimedia



Regionally embedded network core:

Formal and informal relations, knowledge going two ways

Informal relations, knowledge going two ways

International/global periphery :

Formal relations mostly to actors outside the Netherlands ("weak ties"), with knowledge going one-way (e.g. licences, research contracts)

Figure 4 : Systematic representation of the exploration network in pharmaceutical biotechnology (general platform technologies)

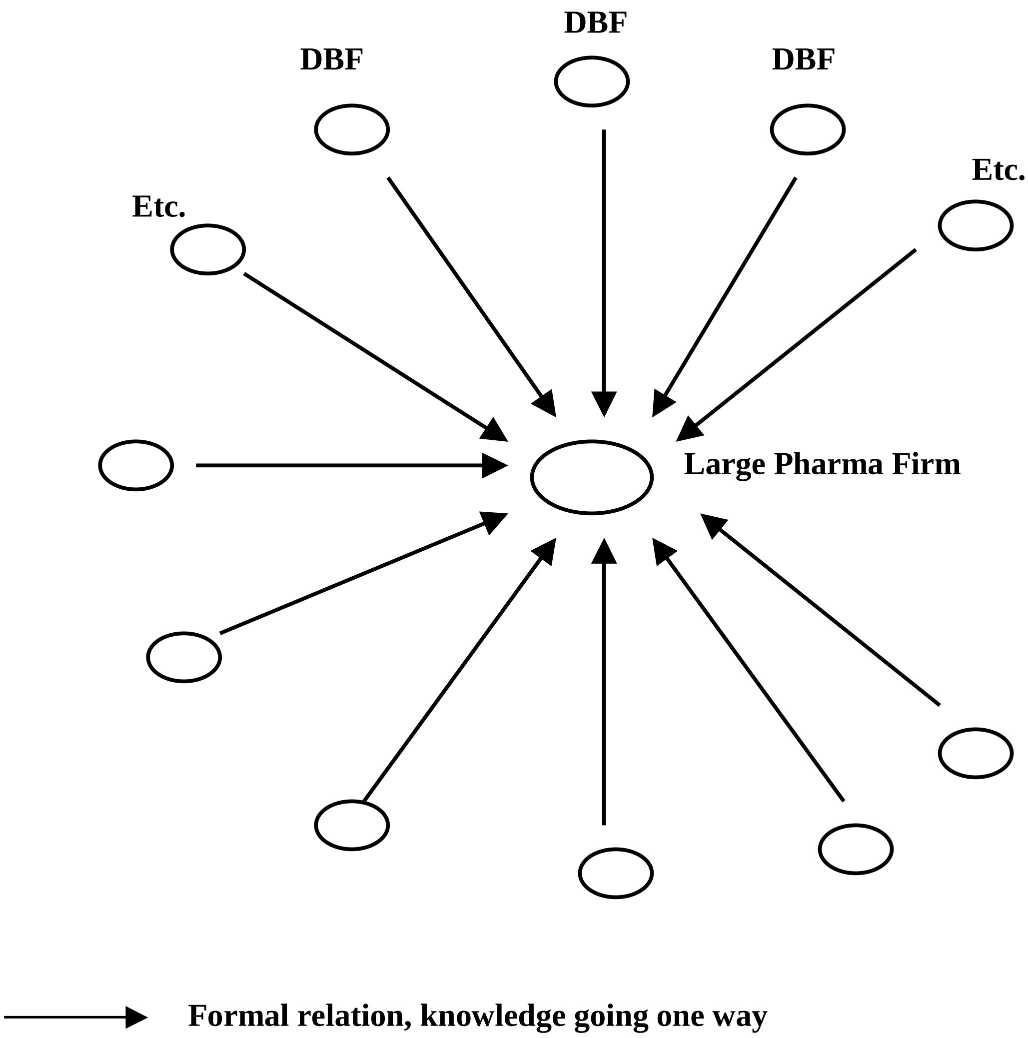


Figure 5 : **Systematic representation of the exploitation network in biotechnology**