Technology Dynamics, Network Dynamics and Partnering

Nederlandse Geografische Studies / Netherlands Geographical Studies

ISSN 0169-4839

Netherlands Geographical Studies 360

Technology Dynamics, Network Dynamics and Partnering

The Case of Dutch Dedicated Life Sciences Firms

Tessa van der Valk

Utrecht 2007

Koninklijk Nederlands Aardrijkskundig Genootschap
Copernicus Institute for Sustainable Development and Innovation

Promotor:
Prof. Dr. M.T.H. Meeus

Co-promotors:
Dr. E.H.M. Moors
Dr. J. Faber

ISBN 978-90-6809-402-2

Graphic design, cartography and figures:
GeoMedia (Faculty of Geosciences, Utrecht University)

Printed in the Netherlands by Labor Grafimedia b.v. – Utrecht

Contents

Figures

Tables

1 Introduction

1.1 Life sciences: an emerging technological field

Organisations active in the life sciences sector make use of developments in modern biotechnology. Modern biotechnology constitutes a broad field of enabling technologies impacting several different industrial sectors, including pharmaceuticals, chemicals, agriculture and food. Due to the potentially pervasive character of this set of enabling technologies their development is considered to be highly important in stimulating sustainable future economic development (Ministry of Economic Affairs, 2004). However, this field is still in a nascent stage of development and can thus be considered emerging. Several characteristics of emerging technologies or technological fields in general and the life sciences in particular are of importance to studying such technologies.

First of all, the science-based character of the life sciences indicates a close connection between technological applications to be developed and commercialised and scientific research conducted at research institutes (Bartholomew, 1997; Meyer-Krahmer and Schmoch, 1998). The scientific and related technological developments evolve rapidly (Orsenigo et al., 2001; Pyka and Saviotti, 2001; Powell et al., 2005), which inherently generates uncertainty for entrepreneurs about which technological opportunities to seize. It is also for this reason that in emerging technological fields, organisations are at least to a large extent dependent on current expectations when making their selection from those different technological opportunities (Van Lente, 2006; Van Merkerk and Robinson, 2006). In practice, this uncertainty results in a wide dispersion of competences and knowledge required for conducting research and development across different organisations within the area of life sciences (see for instance Powell et al., 2005). Also, whereas some of the earliest dedicated biotechnology firms have grown to become so-called 'fully integrated firms', having all competences that are required for conducting R&D and commercialisation in-house, firms increasingly tend to focus on distinct stages in the product development process, covering only parts of the value chain (see for instance Willemstein et al. (2007)).

Another aspect that requires attention concerns the lengthiness of the process of product development, especially when applications in the field of human health are concerned (Powell, 1996; Chiesa and Toletti, 2004; Khilji et al., 2006; Hall and Bagchi-Sen, 2007). The development of a medicinal product can take over ten years from primary invention to market approval, and a large majority of compounds perceived as potentially promising never reach the stage of commercialisation (Gassmann et al., 2004). Also, these lengthy development trajectories are highly capital intensive and highly regulated (Gassmann et al., 2004). Combined, these characteristics of product development imply that firms have to commit their research efforts and spending to highly capital intensive development trajectories, the returns of which will neither be clear, nor certain for years to come. Moreover, while applications of biotechnology are highly regulated, this regulation does not always account for new technological developments, leading to a tendency to accept de facto standards in the absence of stable regulatory frameworks.

A third factor contributing to the uncertainty about the future development of firms working in the field of life sciences concerns public resistance to some of the potential applications, for instance with regard to the introduction of genetically modified organisms into the environment, and the use of embryonic stem cells for research (Bartholomew, 1997; Sager, 2001).

The promises of scientific developments in modern biotechnology have stimulated the establishment of many new organisations aimed at the commercialisation of technological opportunities deriving from scientific developments. These new organisations are based on a specific scientific advance, often achieved at a public research institute or university, resulting in the fact that many of these organisations are university spin-offs. This tendency is closely related to the science-based character of such a high technology field. When comparing new organisations with more established organisations, new organisations have a higher chance of failure. Stinchcombe (1965) has referred to this finding as the *liability of newness*. In general, this liability of newness has been attributed to the lack of social approval of new organisations compared with more established organisations. A specific consequence of this lack of social approval is the lack of stable relationships with other organisations (for instance suppliers) within their environment. This notion of 'liability of newness' has been related to the size of firms in order to address the possibility of a 'liability of smallness' that actually causes an increased failure rate among new firms (as young firms are often also small). Freeman, Carrol and Hannan (1983) showed that even though there is a high level of correlation between the size and age of a firm, both aspects contribute to explaining the differences in failure rates of organisations and thus indicate the presence of a liability of newness as well as smallness.

Comparative studies have so far emphasised the fact that Europe is lagging behind the US with regard to seizing the business opportunities arising from biotechnology developments (see for instance various Ernst & Young reports (2004; 2005)). Compared with other European populations of firms dedicated to biotechnology-related knowledge fields, Dutch firms are particularly young; the number of firms founded during the period between 2002 and 2004 is equal to the number of firms founded in the period 1999 to 2001 and previous periods. This finding differs from the growth in populations of dedicated firms in countries of comparable size, such as Belgium and Denmark, where the peak in the number of newly founded firms occurred in the years 1999-2001 (Critical I, 2006). Overall, the number of firms active in Dutch dedicated life sciences is similar to the numbers in Denmark and Belgium. When controlling for firm age, the average number of employees active within firms is relatively low in the Netherlands compared to Belgium and Denmark (Critical I, 2006). Dutch firms are thus relatively young and small compared to other populations of firms working in biotechnology-related knowledge fields, implying that issues related to the liabilities of newness and smallness are especially relevant in the study of the Dutch population.

In order to overcome the liabilities of newness and smallness, the underlying causes need to be explicated. Delving deeper into the causes of the liability of newness, Singh et al. (1986) found the lack of external legitimacy to be of greater importance than the failure of certain processes operating within the organisation. Enhancing the legitimacy of the organisation thus represents an important way of reducing the chance of failure. In this respect new organisations benefit from the legitimacy of other, more reputable organisations they are perceived to be acquainted with by others. Engaging in partnering with more reputable organisations is therefore of importance given that it enhances social approval and increases the chance of survival of an organisation (Eisenhardt and Bird Schoonhoven, 1996; Stuart et al., 1999; Baum et al., 2000).

Both the overall characteristics of biotechnology as an emerging technological field, as well as the age and size of firms operating within such a technological field, make organisations inclined to engage in partnering. As a result, over the past few decades interorganisational relationships have become the usual practice for organisations working on biotechnology-related developments (Hagedoorn, 2002). The subsequent potential effects of partnering on the survival and growth of organisations active in biotechnology were confirmed in a study by Powell et al. (1996) in which firms that are highly embedded in networks of organisations within biotechnology have a higher probability of succeeding than firms that are not highly embedded. Several other studies have also found a positive relation between engagement in collaboration and organisational performance and survival in the life sciences (Powell, 1996; Stuart et al., 1999; Oliver, 2001; Niosi, 2003). Powell et al. (1996) referred to this tendency as the *liability of unconnectedness*. On the whole, such studies perceive engaging in partnering as something that is generally beneficial to firms. However, given the fact that firms operating in emerging fields face a considerable amount of uncertainty and generally lack sufficient external legitimacy and social approval, the question arises: what factors contribute to the establishment of partnerships by these firms? And how can differences in the number of partnerships of firms be explained? Explicating partnering and thereby answering these questions for Dutch dedicated life sciences firms (DDLSFs) constitutes the central aim of this thesis.

1.2 Theoretical notions on interorganisational collaboration

Definitions of partnerships or related terms for interorganisational agreements range from "capturing many forms of inter-firm cooperation that go beyond mere market transactions" (Nooteboom, 1999: p. 1) to more comprehensive definitions such as voluntary arrangements between firms involving exchange, sharing or co-development of products, technologies or services" (Gulati, 1998: p. 293). Building on Gulati (1998), in this thesis an interorganisational relationship is defined as a cooperative agreement of multiple organisations which can focus on different stages of product or process development and commercialisation, including R&D, production, marketing and distribution.

In this thesis we aim to address partnering at different levels of analysis, namely the level of the network of partnerships as well as the level of the firm and the level of the partnership, and subsequently to link the insights obtained on these different levels. While networks of collaboration reside on the level of the entire population of firms, such networks come about under the influence of different micro-level processes, making firms inclined to search for partners and guiding these search processes. We will now continue to discuss the macro-level dynamics of networks of collaboration, after which we will specifically focus on explanations for partnering residing at the micro-level of the firm.

1.2.1 Macro-level dynamics: development of networks of collaboration

During the past few decades there has been an increase in the number of interorganisational R&D relationships established, especially in high technology sectors (Hagedoorn, 2002). Whereas studies show a relative decline in the number of newly established equity-based collaborations such as joint ventures, an increase is visible in the number of non-equity, contract-based collaborations. The use of such contract-based structures further contributes to the operating flexibility of organisations. In several studies it has been noted that this increased significance of interorganisational collaboration in high technology sectors is not a temporary phenomenon but in due course results in the emergence of actual networks of collaboration (Greis et al., 1995; Powell, 1996; Powell et al., 1996; Stuart, 1998; Kogut, 2000; Pyka and Saviotti, 2001) that complement the internal activities of individual organisations embedded in these networks (Arora and Gambardella, 1990). Studies have so far analysed the composition and structure of networks in the life sciences (Powell et al., 2005) or more specific technological subfields belonging to this field, such as antibody development (Gay and Dousset, 2005). Analysing such networks provides insight into the overall structure of collaborative activity of an industry or sector, which can reveal developments that are not visible by analysing the behaviour of individual firms. A study on networks of collaboration in the life sciences has shown that as networks emerge and develop, the number of different types of organisations increases, as well as the number of types of relationships between these organisations, the latter evolving from R&D to, for instance, also more finance-based relationships (Powell et al., 2005). Another important, general finding of studies on the development of networks of collaboration is the increasing structural differentiation of such networks over time (Gulati and Gargiulo, 1999; Gay and Dousset, 2005) implying that organisations that are well connected become even more connected over time, while it remains difficult for less connected organisations to become more connected. This leads to the formation of so-called hubs in these networks, not accounted for in random networks and small-world networks (Watts and Strogatz, 1998; Powell et al., 2005). In the life sciences, research institutes and established firms have mainly been found to constitute such hubs (Powell et al., 2005). As Gulati and Gargiulo (1999) state, this increasing structural differentiation at some point in time starts to exert an influence on the formation of new partnerships, which is usually referred to as preferential attachment. The extent to which such a differentiated structure is present in the network provides an indication of the extent to which such preferential attachment effects could be present. When studying the dynamics of interorganisational networks, development of their structure as well as the stability of this structure can be determined. Addressing network dynamics enables us to gain insight into the dynamics of collective action (Salancik, 1995).

1.2.2 Micro-level explanations for partnering

Studies aimed at showing the development of networks of collaboration (Gay and Dousset, 2005; Powell et al., 2005; Roijakkers and Hagedoorn, 2006) generally do not provide insight into mechanisms driving the emergence of a partnership, acting on the micro-level. The emerging structure of such a network of collaboration, as stated by Kogut (2000), is “the emergent outcome generated by rules that guide the cooperative decisions of firms” (p. 405). In attempting to explain partnering, such ‘rules that guide cooperative decisions’ as referred to by Kogut (2000) need to be made explicit. Even if a large extent of structural differentiation is present in the network of interorganisational collaboration, the reasons for such preferential attachment remain unclear (Powell et al., 2005). As Powell et al. (2005) state with regard to the field of life sciences "when we consider the rules that guide attachment in this field, we observe that no single rule dominates over all periods" (p. 1188). These rules can simply be related to the connectedness of different actors within the network, but may, among other things, also derive from differences in attractiveness between different organisations that may have an additional cause other than connectedness (Powell et al., 2005: p 1152). Such differences in attractiveness are likely to result from differences in resource endowments of organisations (Gulati and Gargiulo, 1999) indicating that a fitter-get-richer mechanism is operative (Gay and Dousset, 2005).

In general, all participants in a partnership have an economic incentive for doing so (Gulati, 1998), however, this does not necessarily have to take shape in the actual transfer of financial resources from one partner to another. Joint efforts contributing to, for instance, a reduction of the time-to-market of products also constitutes an economic advantage of collaboration.

Several studies have provided insights into explanations for partnering residing on the level of the individual organisation, among which a distinction can be made according to the types of explanations for partnering that are used. While some studies stress the role of (strategic) resource needs (Mowery et al., 1998; Stuart, 1998; Das and Teng, 2000; Hitt et al., 2000; Miotti and Sachwald, 2003) an increasing number of studies on partnering combine resource-based explanations with explanations deriving from a structural sociological, network perspective (Gulati, 1995; Eisenhardt and Bird Schoonhoven, 1996; Gulati, 1998; Stuart, 1998; Gulati, 1999; Gulati and Gargiulo, 1999; Ahuja, 2000). Most of these studies have taken firms as the focal organisation, and have examined the motives of these firms for collaborating with other organisations, including both other firms as well as research institutes. In doing so, the perspective of the partnering organisation has often been neglected (Arora and Gambardella, 1994; Eisenhardt and Bird Schoonhoven, 1996; Ahuja, 2000).

In the Resource-Based View of the firm (RBV), firms are considered to be heterogeneous with regard to their resource endowments and, as resources are limitedly mobile, these differences in endowments lead to sustainable competitive advantages of some organisations compared with others. Based on this limited mobility of resources across organisations, the RBV emphasises the need for organisations to engage simultaneously in the exploitation of existing resources and the development of new ones to ensure future exploitation (Penrose, 1959; Wernerfelt, 1984). The limited mobility of resources across organisations decreases the tradability of these resources, which puts the emphasis on internal development of new resources, instead of obtaining these new resources externally. Whereas market exchange of resources is then problematic, resources of other organisations can be internalised through a merger with or acquisition of these organisations. Over the last decade, an increasing number of studies have made use of resource-based explanations for the formation of interorganisational relationships (Ahuja, 2000). Such studies provide an extension to the traditionally more firm-internally oriented Resource-Based View, and are also closely related to notions deriving from the Resource Dependence perspective, in which organisations are proposed to be dependent on other organisations within their value chain and environment for obtaining access to specific resources. The main focus of this Resource Dependence perspective is then on the ways in which organisations can reduce uncertainty with regard to the use of such external sources of resources and survive in their so-called 'negotiated environment' (Pfeffer and Salancik, 1978).

Rationales for partnering deriving from the Resource-Based View of the firm are primarily based on the resource needs of firms. These resource needs result from, as Van de Ven (1976) indicates, the formulation of "goals that are unachievable by organisations independently" (p. 25). Additional resources that are needed but cannot be obtained through a market transaction are then accessed through collaboration with another organisation. These additional resources can be so-called 'complementary assets', which are often thought to be related to the commercialisation of technological knowledge, but can also be complementary technological knowledge in the case of a systemic technology (Teece, 1986; Barnett, 1990). In this respect, it is the lack of resources of an organisation that makes it inclined to search for other organisations willing to partner. Also deriving from the Resource-Based View is the idea that for a firm to be able to convince a potentially interesting partner to engage in a joint project, the focal firm itself needs to be able to contribute resources to the partnership; i.e. the focal firm needs to be attractive as a partner (Ahuja, 2000; Sakakibara, 2002). This constitutes a paradox: in order to obtain (access to) resources to fulfil resource needs, an organisation already needs to have resources to contribute to the partnership (Eisenhardt and Bird Schoonhoven, 1996; Powell et al., 1996). Authors have referred to this phenomenon as 'resource alignment' (Das and Teng, 2000) or 'strategic or resource interdependence' (Gulati, 1998). A firm's resources determine its potential contribution to a partnership and also other organisations' perceptions of this potential contribution, thereby making the development of resources an intermediary step in increasing the legitimacy of an organisation prior to partnering. Overall, one can think of a focal firm's resource needs as being its *inducements* for partnering, whereas its own resource stocks that make it an attractive partner to others constitutes its resource-based *opportunities* for partnering. This distinction between resource-based inducements and opportunities for partnering constitutes a refinement of the RBV in explaining interorganisational partnering. In this respect, not being able to form partnerships thus derives from a lack of resources available in-house to attract potential partners.

Another possible cause for not being able to form partnerships derives from a structural sociological perspective (Ahuja, 2000). Assuming that potential partners capable of fulfilling the focal organisation's resource needs exist within the environment of this focal organisation, to be able to find such a potential partner the focal organisation needs to have information that can be used to identify such partners. Such information is accumulated by individuals and organisations to constitute their social capital (Burt, 1997). The amount of information available to an organisation directly derives from the embeddedness of this organisation within the network of organisations active in a certain technological field or industry (Stuart, 1998; Gulati, 1999; Ahuja, 2000), which implies that more embedded organisations are better able to identify promising organisations to partner with in the future. Operationalisations of embeddedness that have been used in existing literature include the number of prior relationships of the organisation (Gulati, 1995; Ahuja, 2000) and the prior distance of organisations within the network (Gulati, 1995). In their study on partnering by young semi-conductor firms, Eisenhardt and Bird Schoonhoven (1996) use different aspects reflecting the embeddedness of managers within the sector to address this issue, the rationale for using such a proxy being that young firms have not had time to build a network of collaborations, and depend on the personal networks of contacts of their managers. Different types of networks comprised of different types of relations could thus be of importance here. With regard to the process of partnership formation and evolution Van de Ven et al. (1999) conclude that one of their cases could be most appropriately characterised by "multiple parallel progression of numerous bargaining, commitment and execution events" (p. 148), indicating the lack of predictability of this process of partnership formation and evolution. Such findings also signal the relevance of conducting additional research on explaining the emergence of networks,

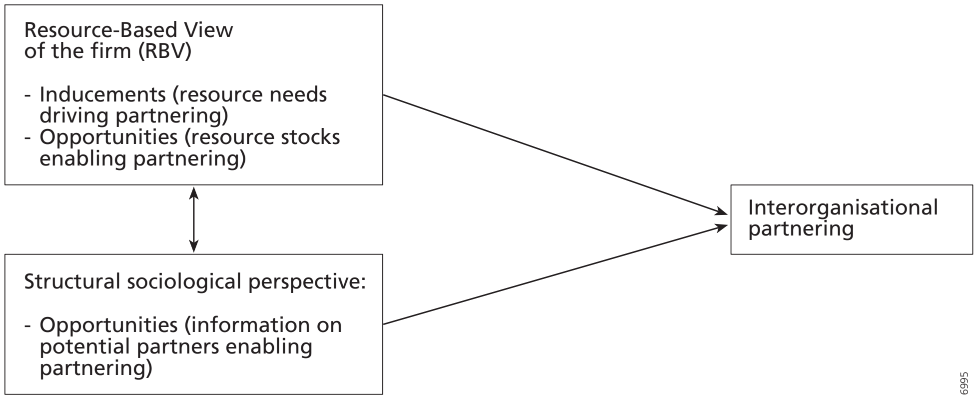

Figure 1.1 Basic conceptual model of interorganisational partnering of this thesis

which, on the micro level, implies explaining the emergence of individual partnerships, using an inducements and opportunities framework derived from the Resource-Based View of the firm.

Figure 1.1 provides an overview of the basic theoretical notions explaining interorganisational partnering that are applied in this thesis.

In general, technological developments are at the core of all the technology-based firms examined here and may therefore be considered pivotal with respect to the content of resource-based inducements and opportunities for partnering. Start-ups active in high technology fields are generally founded on the basis of a specific technological opportunity that is perceived as promising. The invention, related to this technological opportunity, owned by the start-up then constitutes its primary contribution to partnerships with other organisations, either shaped by the actual transfer of this invention or providing access to it, e.g. by out-licensing. Other, more well-established firms are often perceived to provide these start-ups with knowledge related to commercialisation (Powell, 1996; Pyka and Saviotti, 2001) and make use of dedicated technology start-ups to explore new technological opportunities (Pyka and Saviotti, 2001). A more established firm then selects a promising, new technological opportunity by establishing a partnership with a dedicated high technology firm specialised in this specific opportunity.

The distribution of technological knowledge across organisations within high technology science-based fields such as biotechnology contributes to the formation of partnerships in which access to such knowledge is shared. The extent of dissemination of technological knowledge may be perceived as the result of individual firms being highly specialised, and, on the level of the population of firms, a large number of different specialisms being developed, implying that this population of firms is technologically diverse. On the one hand, a high specialisation of technological knowledge of individual organisations may induce the formation of partnerships between these organisations as they require complementary knowledge to conduct R&D. On the other hand, high technological diversity of the population, combined with high specialisation of individual organisations, may limit the number of organisations within the sector that can provide the complementary knowledge required.

Along with a distribution of technological knowledge across organisations and the formation of lateral agreements in which mutual access to technological knowledge is provided by partners, we also see a growing importance of vertically oriented agreements in which each partner contributes knowledge or assets belonging a different stage of the value chain. The increasing importance of partnerships between dedicated biotechnology firms over time found by Owen-Smith and Powell (2004) provides a direct indication of the importance of such lateral relations. Whether a lateral or vertical relation is formed, the technological knowledge of at least one of the partners (namely that of the dedicated technology-based firm) is likely to be of importance to the formation of the partnership.

The importance of explicating technology dynamics also derives from studies on the development of the structure of networks in biotechnology and the life sciences. As was found in a study conducted by Gay and Dousset (2005) on an interfirm collaboration network in the field of antibody development, firms having property rights on the most important inventions in this technological subfield were the most central actors in the network. In addition, Powell et al. (2005) in a study on collaboration networks in the life sciences found that novel inventions exerted a significant impact on the development of the collaboration network as there is a constant addition of new organisations to the network. Organisations already residing in the network 'escort' these newcomers into the network (Powell et al., 2005: p 1178).

Studies referred to in this section all consider partnering an activity that is generally beneficial to organisations. Powell (1996) indicates that "the extensiveness of a firm's network is a strong predictor of survival" (Powell, 1996: p. 208). Gulati (1999) even expands on this by indicating that managers might even consciously contribute to evolving the structure of their network toward a desired state.

Two other theses on life science-related fields in the Netherlands by Oosterwijk (2003) and Gilsing (2003) focused primarily on macro-level developments. Focusing on innovation systems, Oosterwijk (2003) briefly touched on interorganisational collaboration. Gilsing (2003) studied interfirm learning shaped by differing configurations of weak and strong ties within the network of relationships and its co-evolution with the institutional environment. Both of these theses relied to a large extent on secondary data, partly supplemented with interviews. Roijakkers (2003), employing a firm-level, as well as a dyadic and network perspective, studied interfirm R&D partnerships in global pharmaceutical biotechnology.

Compared with these studies, the primary contribution of this thesis is the discussion of technology dynamics and network dynamics generated by a population of organisations on the one hand, and combining these macro-level dynamics with a study of micro-level explanations for partnering, as well as addressing processes of searching for a partner, on the other. In addressing these different aspects of partnering we made use of data on the same population of firms, enabling us to compare the results obtained in the different empirical chapters. On the micro-level we focus on actual resource exchange or sharing mutual access to resources as an explanation for partnering, which derives from the Resource-Based View of the firm (Ahuja, 2000). Furthermore, we take into consideration the structural sociological opportunities for partnering, closely intertwined with the social capital of an organisation.

1.3 The research question, outline and empirical focus of the thesis

The central research question of this thesis comprises two broad questions, one that covers the macro-level context of partnering and one that addresses the micro-level explanations for partnering. On the macro-level, the following question is answered: *How can developments in the macro-level context of partnering by DDLSFs, consisting of technology dynamics and network dynamics, be characterised in the period 2000-2004?* On the micro-level we will address the following question: *What factors related to resource-based inducements and opportunities as well as to structural sociological opportunities contribute to explaining interorganisational partnering by DDLSFs on the micro-level?* To provide an answer to these research questions this thesis comprises four empirical chapters, each addressing different issues incorporated in the research questions.

1.3.1 Outline of the thesis

An overview of the empirical chapters is given in Figure 1.2.

Chapter 2 aims to unravel the technology dynamics initiated by Dutch dedicated life sciences firms. The first question to be answered in this chapter concerns the way in which these technology dynamics can be assessed in such a young and emerging field. Secondly, this chapter aims to analyse these technology dynamics generated by Dutch dedicated life sciences firms. The analysis of technology dynamics should also give insight into the technological positioning of individual firms, such as the extent to which firms combine knowledge of different technological fields or whether they are specialists working in a single specific field. This is considered to be of importance in assessing the potential significance of the specialisation of firms in influencing partnering. Moreover, it is also expected to provide insight into overall patterns of technology dynamics at the level of the population of firms. This insight is necessary to be able to assess whether individual firms share certain common internal knowledge, or whether they mostly differ with regard to the content of their internal knowledge.

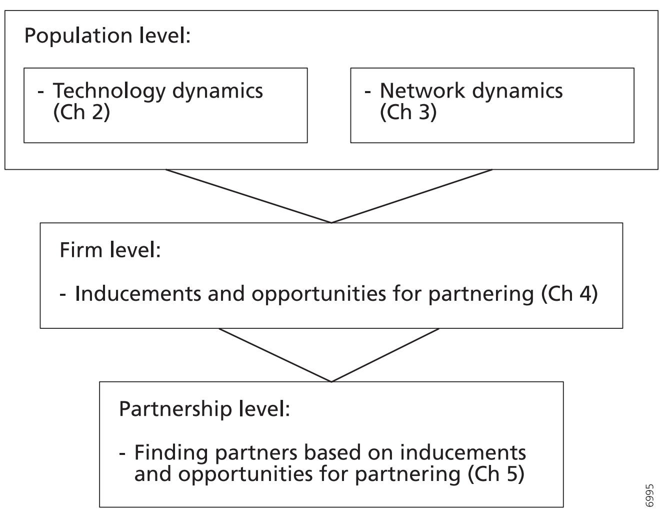

Figure 1.2 Overview of the thesis

Partnering is described and explanations for the observed developments are tested and developed further in Chapters 3 to 5. Chapter 3 aims to reveal the development of the structure of the overall network of collaborations and visualises this development. Given the development of technology described in Chapter 2, Chapter 3 provides insights into the development of partnering on the level of the whole network of relationships, enabling us to reveal the results of partnering of individual organisations on an aggregate level, showing collective action. In this respect, Chapters 2 and 3 address the context in which micro-level partnering takes place. Whereas Chapter 3 is of a descriptive nature, Chapter 4 aims more specifically at finding micro-level explanations for partnering. In this chapter, resource-related explanations for partnering, as described in Section 1.2, are focused on. In doing so, this chapter aims to unravel the explanations for interfirm variations in the number of partnerships a firm is engaged in. The analyses conducted in Chapter 4 are of a cross-sectional nature using data obtained from a written questionnaire. In this chapter, firm-level resource-related explanations are sought for the number of partnerships a firm is engaged in. Chapter 5 aims to describe partnering on the level of individual partnerships based on data obtained from in-depth interviews. In Chapter 5, different types of information sources employed by organisations to find partners are explicitly addressed in order to provide insight into the process of finding partners. While in Chapter 3 of this thesis the network of collaborative relations of the firm is examined, Chapter 5 addresses the extent to which that network constitutes a source of information for finding a new partner. Conversely, it also addresses the extent to which other sources of information enable an organisation to find partners, as well as the nature of these sources. The process of searching for an appropriate partner can at least in part be expected to be directed by inducements and opportunities for partnering that reside at the level of the firm. Namely, whether or not another organisation is considered to be a potential partner is to a certain extent likely to depend on the ability of this other organisation to fulfil the resource needs of the focal firm. Several firm-level characteristics are also taken into account here as they could influence the processes of searching for a partner. The inclusion of these firm-level characteristics in Chapter 5 enables us to relate the findings of this chapter to those obtained in Chapter 4. The final chapter of this thesis (Chapter 6) aims to combine the findings of Chapters 2 to 5, and provide an answer to the central research questions.

1.3.2 Empirical focus of this thesis: Dutch dedicated life sciences firms

The definition of dedicated life sciences firms used here was obtained from the BioPartner Network (BioPartner, 2005) and refers to "those firms that apply the possibilities of organisms, cell cultures, parts of cells or parts of organisms, in an innovative way for the purpose of industrial production. They may also supply related services, and hardware and software." (p. 188). This definition is based on the definition of life sciences used by the Dutch Ministry of Economic Affairs, and is somewhat broader than just firms focusing solely on the modification of cells and organisms. The precise biotechnology-related subfields these firms are working on will be further clarified in Chapter 2 of this thesis. Additional general conditions for the inclusion of firms in this study are: 1) that the firm conducts R&D activities in technological fields belonging to the life sciences, as defined above; 2) that the firm is located in the Netherlands; 3) that the firm is registered at the Dutch Chamber of Commerce; and 4) that the firm is an independent entity (BioPartner, 2005: p 188). Additional conditions are applied in some of the following empirical chapters. These conditions are then further clarified in the relevant chapters.

Most of the data used for analyses in this thesis were obtained from the annual written survey conducted in the name of the BioPartner Network by means of a questionnaire distributed among the population of firms whose boundaries were defined above. In this thesis, the editions of 2002 and 2004 are primarily focused on given that 2002 was the first year in which the questionnaire was relatively comprehensive since the establishment of the BioPartner Network in 2000. Moreover, as will be shown in the next section, relatively many firms were founded during this period, enabling the study of the early development of dedicated life sciences in the Netherlands. The data derived from these written questionnaires have been supplemented with website information on technologies in use (Chapter 2). Additionally, interviews with managers of DDLSFs were conducted to obtain information on partner search (Chapter 5).

2 Patterns in the dynamics of emerging technologies: conceptualisation, measurement and visualisation

2.1 Introduction

Emerging technologies in high technology, knowledge-based sectors, such as biotechnology and nanotechnology, are characterised by rapid development in terms of significance and development rate of new ideas and technologies. A gradually broadening range of scientific and technology (knowledge) fields is also included. These fields are constantly changing as science and technology progress over time. The importance of technological change in these dedicated high technology sectors is not well understood as yet in terms of their current technologies and probable future developments. This is partly due to the embryonic, emerging character of these new technologies, leaving many aspects still uncertain or unarticulated. For emerging technologies the general level of standardisation is still low. There are high expectations, but also many uncertainties whether these expectations will be realised. With regard to innovations in biotechnology, for instance, the controversies regarding genetically modified organisms (Jolivet and Maurice, 2006), the patentability of genes, and the uncertain demand for personalised medicines are evident. While applications of biotechnology are highly regulated, this regulation does not always account for the newness of some of the inventions, leading to a tendency to accept de facto standards in the absence of stable regulatory frameworks. Such aspects generate uncertainty with regard to the direction of technological change. Prior to any attempt to steer the future direction of technological developments using policy measures, developments that have occurred so far need to be explicated. In this chapter we examine technology dynamics generated by Dutch dedicated life sciences firms (DDLSFs).

Patent data have been a regular source of information to gain insight into technology dynamics (see for instance (Duysters and Hagedoorn, 1998; Malerba and Orsenigo, 1999; Breschi et al., 2003; Saviotti et al., 2005)). One of the advantages of using patents in studying technological developments over time is that they can easily be analysed as a temporal sequence using either the date of application, publication or granting. However, in emerging technological fields the applicability of patent data for the analysis of technology dynamics is questionable. First of all, the firms active in such a field, and therefore contributing to technological developments, are generally young and small firms. Many of these firms do not have patents yet, partly because of the high costs involved and the difficulties in protecting the patent when infringement occurs (Lemarié et al., 2000). Secondly, in biotechnology many of these firms are spin-offs from research institutes that make use of knowledge that has already been patented by these research institutes and consequently these patents cannot always be traced back to the firm. This particular situation is not unique for the Dutch life sciences population but may apply to all technological fields in which start-ups are deemed to contribute significantly to technological change. Instead of applying patent analysis we have therefore conducted the analysis of technology dynamics by focusing on technologies *in use*, as was also done by Lemarié et al. (2000). In order to incorporate a temporal aspect in this analysis of technologies in use by start-ups founded between 2000 and 2004 we use the year in which the firms were founded. This is because they are not likely to have completely changed their technology portfolio in such a relatively short period of time. This will be further elaborated on in Section 2.3.

In Innovation and Science Studies there are several traditions that deal with patterns of technology dynamics. These include the tradition of diffusion research, the evolutionary approach based on the socio-cognitive and institutional approach, and the technological regimes approach linked to industrial economics. The question is whether these approaches are useful to study the dynamics of emerging technological fields. In such fields demand is unclear or not articulated yet reducing the applicability of diffusion research. A fruitful approach that has been applied to emerging technologies is the socio-cognitive and institutional approach (Bijker and Law, 1992; Garud and Rappa, 1994; Van de Ven et al., 1999; Rao and Singh, 2001). These studies have provided in-depth analyses of the ways in which a specific invention can evolve in the laboratory and new business ventures, and very often report the shifting evaluation criteria as to the function and quality of inventions, even over short periods of time. They show how volatile the further development of an invention is, and how early patenting can become a deadlock in the competition for attention and resources between various technological options. As opposed to the cases of specific inventions addressed in these studies, this study aims to address technology development at a much more general level, namely biotechnology-related developments driven by the population of DDLSFs.

In emerging technological fields, technological regimes are only in the nascent stage of development. Building on earlier works on technological regimes we will develop a set of concepts and measures that enable a systematic analysis of patterns of technology dynamics in emerging technological fields. From the technological regime literature (Nelson and Winter, 1982; Malerba and Orsenigo, 1996; Breschi et al., 2003) we derive the notion of *technological opportunities*, and from the population ecology literature we derive the *founding of firms* over time. As opposed to most of those studies the key indicators are not patents but technologies in use, and not sectors but the founding of firms within a sector.

The central research question of this chapter then becomes:

How can patterns of technology dynamics of emerging technologies be conceptualised in general? And more specifically with respect to the case of Dutch dedicated life sciences firms: *Which patterns of technology dynamics could be discerned at Dutch dedicated life sciences firms, newly founded in the period 2000-2004?* This central research question brings up several additional research questions which are examined in this chapter:

1. *Which technological fields can be discerned in modern biotechnology, and how can they be classified?*
2. *What patterns in the development of the technological diversity of the population of newly founded firms could be discerned for subsequent annual populations of these newly founded firms?*

3. *To what extent are Dutch dedicated life sciences firms newly founded in the period 2000-2004 specialists, focusing on one specific technological (sub)field, and to what extent do they combine various technological fields?*

What are the contributions of this chapter to prior literature? Recently, several studies have focused on organisational aspects and their dynamics with regard to high technology firms, especially where firms working in biotechnology are concerned (Bigliardi et al., 2005; Nosella et al., 2005; Terziovski and Morgan, 2006; Hall and Bagchi-Sen, 2007; Willemstein et al., 2007). In these studies, the technologies focused on by these firms are left implicit, and attention is primarily given to the organisational aspects of innovation processes. For example, in the process model of 'Biotech innovation management' as presented by Khilji et al. (2006), 'science and technology' is proposed to be the starting point of the innovation process, whereas little attention is given to the contents of this 'science and technology'. However, as Kash and Rycroft (2002) state, "it is the simultaneous evolution of technology and organisations that creates novelty and variety in technological products, processes and in the networks themselves" (p. 582). This chapter aims to complement such studies focusing on organisational dynamics by unravelling technology dynamics.

Compared to population ecological studies, our approach pursues a more detailed analysis of technology dynamics. We do not limit ourselves to the growth of one specific population e.g. of tissue engineering firms only, but we try to develop measures for shifts in the shares of specific technological subfields over time. We will focus on technological opportunities and ask whether these technological opportunities diverge or converge over time, or: whether there is a common direction in which this technological field develops or whether there is no direction visible at all.

Another contribution of this chapter is that we address technological combinations made by individual firms across the opportunity set. This is very important because other research has shown how important the initial technologies of firms are in determining future developments. Lemarié et al. (2000: p. 9) show that the technologies in use by a sample of UK, German and French biotechnology firms could be traced back to the year of their foundation. The internal renewal of technologies is thus not the main driver of technology development, but the founding of new firms is. For this reason it is interesting to see whether, and if so, how many firms already combine technologies at the time of their foundation. One might argue that the more combinations of technologies are made by firms across a set of technological opportunities, the higher the number of innovation opportunities in that population. As indicated by McKelvey et al. (2004), the development of new knowledge and technologies involve ongoing, complex, dynamic processes within society and, in turn, these affect the development of innovation opportunities (McKelvey et al., 2004). But then again, it might also be that the broader the technologies in use, the higher the risk of not accumulating enough resources to commit to further development of the invention. Such further development might then be hampered.

The policy relevance of this study derives from policy debates in the EU concerning emerging technologies such as biotechnology. These developments started much earlier in the UK, France and Germany than in the Netherlands. Only in the late 1990s was biotechnology identified by the Dutch government as an important enabling technology for the development of a national knowledge-based economy, which is regarded as a prerequisite for sustaining societal wealth and welfare in the Netherlands in the near future. An analysis of the Ministry of Economic

Affairs carried out in 1998 showed that the Dutch biopharmaceutical sector was lagging behind those in neighbouring countries, the main barriers being that Dutch knowledge institutes lacked a business culture (Ministry of Economic Affairs, 1999). The results of scientific research were seldom commercialised. There was not enough venture capital available for start-ups and there was a shortage of facilities, such as office and laboratory space (Ministry of Economic Affairs, 1999). From the year 2000 onwards, possibly stimulated by government initiatives that started in these years such as the BioPartner Network programme, opportunities deriving from developments in modern biotechnology have led to the founding of 109 new firms focusing on products and processes based on these developments and related supporting technologies (BioPartner, 2005). These firms are referred to here as dedicated life sciences start-ups, as was done by BioPartner (2005). In this research we study the technologies used by these firms and relate them to common technological fields in biotechnology.

Today, the Dutch life sciences sector is still in an early stage of development and consists of about 160 primarily small, privately held, often loss-making, entrepreneurial firms. These start-ups mostly begin as spin offs from Dutch academic research groups trying to commercialise new research findings in the biotechnological field. It is expected that the surviving start-up firms will be able to contribute to the development of a new high technology, knowledge-based industry within the Netherlands.

The chapter is organised as follows. Section 2.2 will present some theoretical notions on concepts of technology dynamics at the population level as well as the level of the individual firm. The opportunity matrix will be introduced, leading to a conceptualisation of patterns of technology dynamics. Section 2.3 will discuss the rapid development of modern biotechnology in the light of the evolving generations of biotechnologies over time, and gives a classification of the important science and technological fields in biotechnology developments in general. It will subsequently describe the research methodology applied. Section 2.4 will present the results of these analyses. In Section 2.5, the findings will be discussed. Finally, Section 2.6 will give a presentation of the conclusions drawn from these results as an answer to the central research questions stated above.

2.2 Theoretical notions on patterns of technology dynamics: Towards a new conceptualisation

In population ecology there is a line of work that addresses firm foundings and technology cycles. The research on technological regimes and r-to-K transitions in population ecology comes closest to relating technology development to firm foundings as pursued in this study. In emerging technological fields the population of organisations dedicated to these fields is low at first. The number of organisations increases over time as specialist firms identify and subsequently exploit 'new resource opportunities' (Baum and Rao, 2004). These specific resource opportunities can be perceived as niches, in which specialist organisations attempt to exploit their relatively narrow knowledge portfolios (Brittain and Freeman, 1980). As a population grows, the availability of resources decreases, which reduces the chances of survival of specialist firms and induces the appearance of generalist organisations capable of competing "…on the basis of efficiency for the mass market…" (Baum and Rao, 2004: p. 228). This transition towards competition based on efficiency in which generalist firms prevail is referred to as r-to-K transition. As was stated by Baum and Rao (2004) "Often underlying r-to-K transitions are technology cycles that shape appropriate organisational forms…(p. 229)". The idea is that technology generations are replaced once they reach their natural limits. This natural limit is defined by the moment when a generation no longer produces viable technological options that are comparatively more attractive than competing new generations do (Duysters, 1995). Schumpeterian enterprises play a dominant role in the creation of new combinations during this initial period. In this respect, emerging technological fields may be expected to be characterised by an increasing number of small, young, specialist organisations who fill their own specific technological niche. This population of organisations can then be regarded as homogenous in terms of the breadth of the technology portfolio of the individual organisations. This breadth is relatively small given that the portfolios are specialised. However, the population is also regarded as heterogeneous in terms of the specific content of these portfolios. Such a specialisation of firms in biotechnology was also indicated by Pyka and Saviotti (2001) who stress the role of such firms as either translators of new knowledge or explorers of this knowledge. Orsenigo et al. (2001) refer to these new organisations as 'specialised technology originators' (p. 490).

Over time, strategies with regard to technology development of successful firms might be imitated (Brittain and Freeman, 1980), but the increasing competition for resources within a specific niche might also induce variation within the growing population over time.

To develop an in-depth conceptualisation of variation, and to link technology dynamics and founding more closely we take up one of the elements advanced by Malerba and Orsenigo (1996) namely the *opportunity conditions* and elaborate it further. They relate technological opportunities to the potential of innovation within a specific field (Malerba and Orsenigo, 1996: p. 453). These technological opportunities are not stable over time, on the contrary, their extent and focus change over time, as new technological (sub) fields emerge and others become more established. Moreover, the rate of technological progress "depends on the technological "distance" from limits, both prior and subsequent." (Ayres 1994: p. 67). Thus, the technological opportunities partly depend on non-economic factors and constraints, such as the physical properties of materials and also on funding for research. Technological change is therefore not a smooth or uniform process in time (Ayres, 1994). Barriers and subsequent breakthroughs punctuate it. These barriers are limits inherent to a given physical configuration.

The extent to which these technological opportunities described here are taken up is closely related to the competencies of different actors within the technological field, and these competencies are a source of heterogeneity among these actors (Cantner and Pyka, 1998). On the one hand, opportunities can be utilised by established firms with relatively established technology portfolios. This would possibly require diversification of these technology portfolios. However, the likelihood of diversification, especially into unrelated technological fields, is reduced by the bounded rationality of these established actors (Simon, 1957). Moreover, inertia caused by specialisation contributes to the relative stability of the technology portfolios of established firms (McKelvey, 1996; Breschi et al., 2003), also more specifically where firms active in biotechnology are concerned (McKelvey, 1996). On the other hand, especially in high technology sectors such as biotechnology, newly founded firms have been perceived as the main drivers of technological change and they thus could be perceived as the type of actor most likely to utilise these opportunities for innovation. In practice, established firms have been seen to engage in partnering with these new technology-based firms, this partnering functioning as a mechanism to explore new technological opportunities (Pyka and Saviotti, 2001).

In the remainder of this section, we make an explicit distinction between the level of the population of firms and the level of the individual firm. We examine technology dynamics at these two intertwined levels of analysis.

2.2.1 Technological diversity of the population of newly founded firms

Adhering to a population-level perspective, we aim to provide insight into general developments of technological fields in Dutch biotechnology. This enables us to examine the development of technological fields over time as well as determine whether there are technological kernels and how they develop.

Population-level technology dynamics is conceptualised as *technological diversity of the population,* indicating that in a sector the number of technological fields can change over time, as can the extent to which firms are working in these fields. To qualify the notion of technological diversity, we use the *nature of changes* in technological diversity. Over time, the technological diversity of a population can either decrease, increase or remain stable. This nature of development in diversity is conceptualised by the notions of convergence[1] and divergence. We speak of technological convergence when technological diversity decreases over time, and of technological divergence when the technological diversity increases over time.

In order to evaluate developments in the technological diversity of the subsequent populations of newly founded firms, we operationalise this concept using two indicators. On the one hand, we incorporate a factor addressing the *quantitative* aspect of this diversity, namely a measure of the number of different technological fields covered by the population of newly founded firms. On the other hand, we also incorporate a more *qualitative* aspect of diversity, namely related to the variation in the relative contribution of each of the technological fields. This would imply using both the number of different technological fields represented over time as well as a measure for the variation in the prominence of these different technological fields. In this study, we use the standard deviation (SD) of the annual shares of the different fields as a measure of their relative prominence: a standardised way of measuring the deviation from the mean annual share (Wonnacott and Wonnacott, 1990).

Combined, developments in the number of fields and the SDs of the shares of these fields over time give us some insight into the question whether there is some extent of technological convergence, divergence or stability in the population of newly founded firms over time. Our interpretation of the results according to convergence/divergence/stability is given in Table 2.1.

Possibly counter intuitively, decreases in the SD of the annual shares of the technological fields indicate technological *divergence,* as different fields are more equally addressed and technological kernels dissolve. Increases in the SD of the annual shares of the technological fields addressed are a signal of technological *convergence* of the population of firms, as the prominence of certain fields compared to others increases, indicating the emergence of technological kernels. On the other hand, an increase in the number of technological fields addressed is a signal of

Table 2.1 Operationalisation of patterns of technology dynamics at the level of the population

	No. of fields: ↑	**No. of fields: stable**	**No. of fields: ↓**
SD(shares): ↑	Indeterminate	Convergence	Convergence
SD(shares): stable	Divergence	Stability	Convergence
SD(shares): ↓	Divergence	Divergence	Indeterminate

technological divergence of the population. When combining developments in the number of fields addressed and in the SD of the annual shares, nine different combinations can be of relevance, as is shown in Table 2.1. When developments in the SD of the shares and number of fields have opposing effects on patterns of technology dynamics of the population, we are not able to weigh these effects and determine an overall effect, hence the term 'indeterminate' in Table 2.1. The trend in the relative share of each subfield at t_n as compared to t_{n-1} indicates whether technological kernels emerge with a relatively larger share as compared to other subfields.

These patterns of convergence, divergence, or stability are expressed at the level of the population and thus at the level of a technological field in general. In this study, these patterns are composed of patterns initiated at the micro-level, namely by newly founded firms. This implies that shifts in the annual shares of technological fields are initiated at the micro level by differences in the technological positioning of newly founded firms over time. These technological opportunities as perceived by these newly founded firms drive subsequent technological developments within the sector. Therefore, we link these developments in technological fields to technology development within firms, by providing an overview of the different technologies that firms combine. These technology portfolios of firms represent the building blocks that constitute patterns of technology dynamics at the level of the population.

2.2.2 Technology dynamics visualised as movement of subsequent populations of newly founded firms across an opportunity matrix

The first step in *visualising technology dynamics* at both the level of the firm and the technology, is to construct a so-called *opportunity matrix*, as given in Figure 2.1. The rows and columns of this matrix define the technological subfields within a technology. Technology dynamics visualised in this way is a function of the availability and distribution of knowledge within the population of firms.

Each founding of a firm can be filled out in this matrix. A founding of a firm on the diagonal implies that an entrepreneur starts business activities as a specialist. Besides this option, a firm can combine two or more technological fields at founding and thus be founded based on

	TF1	TF2	TF3	TF4	TF5	TF6	TF7	TF8	TF9	TF10
TF1										
TF2										
TF3										
TF4										
TF5										
TF6										
TF7										
TF8										
TF9										
TF10										

6995

Figure 2.1 Opportunity matrix of technology development heterogeneous knowledge, belonging to more than one technological field. As Levinthal (1998) argues, a major source of opportunities for innovation is 'speciation', i.e. the migration and application of an existing technology to other and new application domains. Although the initial technological shift from one domain to another may be small, the speciation event may trigger a substantially new and divergent trajectory. New lineages may also emerge as the result of hybridisation of two formerly distinct technologies in a common application domain. Moreover, innovation is not necessarily equated with change of a single technology. Rosenberg (1982) addressed the role of complementarities: a particular technology can move forward because of inventions and improvements of other technologies. This is also the case for biotechnology. 'Older' DNA/protein based technologies are now complemented by genomics-based 'newer' technologies such as bioinformatics and proteomics.

Subsequently, a question that arises is how a population of newly founded firms fills the matrix, and whether they fill mainly diagonal cells of the matrix, or do they also fill off-diagonal cells, and which of the possible combinations of technological fields are prominent. We are also interested in whether these prominent combinations remain prominent over time.

After founding, firms can diversify their technology portfolio in a related or unrelated manner, which would imply movement of this firm across the cells of the opportunity matrix, thereby becoming either a knowledge or a market diversifier. The direction of such movements is driven by either a business (market) or knowledge purpose. Movement across the opportunity matrix requires resource inputs, which includes financial as well as knowledge resources. These resource needs can be fulfilled by a) hiring additional competencies, and b) performing research that extends available competencies across its disciplinary borders, and finally c) partnering with entrepreneurs or scientists that occupy other cells (i.e. other technological (sub)fields) in the opportunity matrix. Again, the viability of options is co-determined by combining existing competencies with funding opportunities and this viability is often firm-specific (Teece et al., 1997). In this study, we do not empirically address diversification strategies of individual firms over time, as we study newly founded firms.

Whereas such an opportunity matrix represents a useful instrument for studying technological change, it also has certain limitations, most strikingly in that it enables visualisation at at most, a two-dimensional level. This implies that a firm can only be attributed to two technological fields. In order to overcome this limitation of the opportunity matrix, we use network visualisation software NetDraw (Borgatti, 2002) to depict the two dimensional opportunity matrix, and generate figures in which the nodes will be the different technological fields that have been discerned and linkages between these nodes will represent firms that combine knowledge of two different fields. Firms that combine knowledge of more than two different fields can be added thereafter, by adding similar styled linkages to the figure that connect these three or more technological fields that are combined. New combinations between technological fields made by firms over time are depicted in these figures as linkages between nodes (technological fields) that emerge over time. A similar methodology was also used by Saviotti et al. (2005), for examining the knowledge bases of firms using the patents of these firms and their corresponding patent categories.

In the next section we will start with a description of the development of modern biotechnology and a classification of technological fields within this sector, which could fill the first row and first column of the sketched opportunity matrix. Subsequently, further clarification of the research methodology employed, including the method of collecting the firm-level data on the inclusion of technological fields in their technology portfolios, will be provided

2.3 Development of modern biotechnology, data collection and measurements

Various generations of technological change could be distinguished following the rise of the biotechnology industry over time. Prior to the 1880s plant extracts had been the most important product source. From 1880 until 1930, physiological chemistry and the extraction of natural products came up, and synthetic organic chemistry became more important. During the 1930-1960s organic chemistry and soil microbiology became the most important scientific fields, with the 1950s being the Golden Age of synthetic drug discovery (Santos, 2003). From 1953 onwards, based on the discovery of the structure of DNA by Watson and Crick, an era of new biotechnology products and processes began.

The differences between the old and the new techniques of biotechnology can best be described as an evolution over three distinct phases of technological change, usually described as first, second and third generation biotechnologies in their evolution over time (Acharya, 1999).

First generation biotechnology describes the older techniques of biotechnology, based on the use of bacteria in fermentation, bread and cheese making, and the leaching of metal ores from mine sites. It includes natural processes which occur without much systematic application and were discovered through empirical observation rather than scientific analysis.

Second generation biotechnology includes all those new processes and products based on new scientific disciplines such as biochemistry, microbiology and enzymology, until the rise of recombinant DNA technology and the use of molecular biology techniques in the 1970s.

Third generation biotechnology is the result of the breakthroughs in molecular biology in the early 1970s. Scientists had developed the knowledge and tools to intervene directly at the gene level: the genetic engineering technique was born and revolutionised modern biotechnology with recombinant DNA (r-DNA) technology and the development of monoclonal antibodies as most important technologies. The development of the r-DNA technology led to various new branches of products based on genetic engineering tools. The first branch came up in the 1980s and was based on r-DNA versions of natural products, such as recombinant human insulin, growth hormone and interferon. The second branch of r-DNA techniques, appearing in the 1990s, began to use protein engineering to produce slight variations on the natural r-DNA based products of the first branch. Such protein engineering techniques involve the identification of different functions performed by the different parts of a natural molecule, followed by a modification of specific parts of the molecule to improve its performance (site-directed mutagenesis), e.g. engineered insulins, and post-translational engineering: glycosylated products (Walsh, 2005). In 2003 the complete sequence of the human genome had been mapped in the HUGO project, making extensive use of bioinformatics to ease the sequencing procedures. Firms at the forefront of biotechnology research were then moving out of the second branch of protein-based technologies, to concentrate more on the third branch of small molecules, designed by bio-informatics, combinatorial chemistry, rational drug design and high-throughput analysis techniques (Gassmann et al., 2004).

Furthermore, Walsh (2005) states that while the focus is now on protein-based biopharmaceutical products, mostly being engineered products (via protein engineering and post-translational engineering), alternative production and delivery systems will come up in the future, such as transgenic plant produced products and non-parenteral delivery routes. In addition, more attention will be given to nucleic acid-based therapeutics, such as gene-therapy (gene-therapy based cancer products), anti-sense technology, RNA interference technology and aptamers, genomics-based technologies, and stem cell based therapies.

2.3.1 Towards a refined classification of technological fields in third generation biotechnology

Modern biotechnology is a wide emerging technological area and comprises a broad range of scientific and technological fields. Especially in the third generation, from 1970s onwards, many different fields have been involved, and new technological fields, such as bio-informatics, proteomics and pharmacogenomics have been emerging. In order to analyse the patterns of technology dynamics within this third generation of biotechnology developments this chapter will first develop a refined classification of the discernable technological fields. In order to unravel the precise scientific and technological (sub)specialisations within broad technological fields we are not using the broad IPC-codes involving biotechnology, which are often used in patent studies, such as C07H (sugars, derivatives of nucleotides, nucleotides, nucleic acids) or C12S (processes using enzymes or micro-organisms to liberate, separate or purify pre-existing compounds).

We started with the official OECD classification of biotechnology fields (OECD, 2001), identifying the following five broad categories (McKelvey et al., 2004): 1) DNA (the coding); 2) Proteins and molecules (the functional blocks); 3) Cell and tissue culture and engineering; 4) Process biotechnology; and 5) Sub-cellular organisms.

Taking into account all the new developments occurring in the various branches of third generation biotechnology, we considered this OECD classification into five technological fields too small to cover all the various biotechnology developments. Based on the work of Campbell et al. (1999), Crommelin and Sindelar (2002), Oosterwijk (2003), and Walsh (2005) on future directions of biopharmaceuticals, we added various scientific and technological fields and subfields to the five OECD categories in order to complement them with more recent insights (see Table 2.2).

As can be observed in Table 2.2, some of the distinguished technological fields have been divided into subcategories to cover all the important technologies related to the main technological field. For example, the technological field of 'Proteins and other molecules' covers five subcategories: synthesis and sequencing of proteins and peptides, isolation and purification of proteins, protein engineering, proteomics, and naturally derived products.

Starting from the classification in 11 main technological fields of biotechnology and the involved subcategories (see Table 2.2), an innumerable number of combinations are possible. From a market development perspective it is interesting to explore which Dutch firms are so-called 'boundary spanners' in the biotechnology business, crossing the borders of their own knowledge and technological field and looking for opportunities to combine the knowledge of different technological fields. Which technological fields are then expected to be combined in practice? We will give some illustrative examples:

Table 2.2 Classification of technological fields and subfields in modern biotechnology

1. **DNA/RNA***;* all the topics on DNA coding, and transcription of DNA into RNA. Subfields:
    a. *Gene probes, genetic engineering*
    b. *DNA-RNA sequencing/synthesis/amplification/purification*
    c. *Functional and comparative genomics, structural genomics*
    d. *Transgenic animals*
    e. *DNA microarrays and oligonucleotide microarrays*
    f. *Single Nucleotide Polymorphisms (SNPs)*
    g. *Pharmacogenetics and pharmacogenomics: related to response to drug treatment*
    h. *Oligonucleotides: short segments of DNA*
        I. Anti-sense technology/triplex technology
        II. Aptamer technology
2. **Proteins and other molecules**: all the topics on functional peptide and protein blocks. Subfields:
    a. *Sequencing/synthesis of proteins and peptides*
    b. *Protein isolation and purification*
    c. *Protein engineering*
        I. Site-directed mutagenesis
        II. Enzyme engineering
        III. Fusion proteins
        IV. Antibody engineering
    d. *Proteomics*
    e. *Naturally derived products*
3. **Cell and tissue culture and engineering**: all the topics on cell and tissue cultures. Subfields:
    a. *Cell/Tissue culture, cell line development*
    b. *Tissue engineering*
    c. *Cellular fusion*
    d. *Vaccine/immune stimulants*
    e. *Embryo manipulation*
4. **Process biotechnology**: all the topics on bioreactors, fermentation, bioprocessing, bioleaching, biopulping, biobleaching, biodesulphurisation, bioremediation and biofiltration.
5. **Gene and RNA vectors***:* all the topics on sub-cellular organisms. Subfields:
    a. *Gene therapy*
    b. *Viral vectors*
    c. *DNA transfer*
6. **Bio-informatics and development of tools***:* including the following subfields:
    a. *Construction of databases on genomes*
    b. *Modelling complex biological processes, including systems biology*
    c. *Instruments and devices applied to biotechnology*
        I. Bioinformatics
        II. High-throughput screening
        III. Combinatorial chemistry
        IV. Chiral chemistry
        V. 3-D structures engineered proteins (crystallography, NMR, spectroscopy, protein modelling)
7. **Nanobiotechnology**: applies the tools and processes of nano/microfabrication to build devices for studying biosystems and applications in drug delivery, diagnostics etc.
8. **Glycobiology***:* synthesis of glycolipids and glycoproteins (carbohydrates, branched oligosaccharides, covalently bonded to lipids and proteins respectively), important in cell-cell recognition.
9. **(Bio)materials**: includes material intended to interface with biological systems to evaluate, treat, augment or replace any tissue, organ or function of the body. These can be used to make implants, prostheses and surgical instruments.
10. **Bio assays***:* test to determine the strength or biological activity of a substance, such as a drug or hormone, by comparing its effects with those of a standard preparation on a culture of living cells or a test organism.
11. **Drug targeting***:* a strategy aiming at the delivery of a compound to a particular tissue of the body.

From a market perspective, it could be argued that while the broad technological fields of DNA/RNA handling (category 1) and protein synthesis/sequencing (category 2) are quite different, they might possibly be combined by means of new genomics-based technologies such as pharmacogenomics, proteomics, and metabolomics.

Synthesis of specific DNA/RNA fragments (category 1) or of specific peptides or other molecules (category 2) is in practice often combined with identification techniques of those fragments or molecules (category 6). This identification then gives possibilities to apply these molecules as antibodies or as vaccines (category 3). In this way, categories 1,2, and 3 are also often combined.

Firms exploiting process biotechnology (category 4) often have to deal with enzymes and fermentation processes. These enzymes are proteins or DNA/RNA molecules with a specific catalytic function. The synthesis/sequencing and engineering of these enzymes (proteins/DNA/RNA) fall in category 2 and category 1 respectively. In addition, antibody engineering, fusion proteins (category 2), and cell and tissue engineering, especially vaccine/immune stimulants (category 3) are often combined. And also viral RNA inhibition (category 1) via immune suppression (category 3).

Bio-informatics could in practice be regarded as a broad enabling technology for more technological (sub)fields (category 6). It is based on knowledge of genomics and proteomics (category 1 and 2), applying modern IT technologies, building electronic databases of genomes and protein sequences, and computer modelling of biomolecules and biologic systems. Furthermore, bio-informatics firms (category 6) sometimes deliver structural data for potential drug targets to firms developing drug delivery systems (category 11).

And as a last example, firms working on biomaterials (category 9) often also address cell and tissue culture and tissue engineering techniques (category 3) as these are often the biological systems the material is intended to interface.

In summary, this section showed the technological developments in various generations of biotechnology, especially the most recent third generation modern biotechnologies. In order to analyse technology dynamics patterns within this third generation of biotechnologies we needed a refined classification of involved technological fields and subfields. A third generation biotechnology classification of 11 main categories and related subcategories of technological fields has been provided. In the following section, the method of data collection will be explained.

2.3.2 Research population and data gathering

The population of firms studied here comprises all of the DDLSFs that were established in the period 2000-2004. Criteria for the inclusion of these firms were that they needed to be registered at the Dutch Chamber of Commerce and have life sciences as their core business. The definition of life sciences used here is derived from the BioPartner Network (BioPartner, 2005) and refers to "those firms that apply the possibilities of organisms, cell cultures, parts of cells or parts of organisms, in an innovative way for the purpose of industrial production. They may also supply related services, and hardware and software." (p. 188) This definition is somewhat broader than just firms focusing solely on modern biotechnology. In total, 93 firms were included in the study.

In order to provide an overview of technologies focused on by DDLSFs, these firms were characterised according to their in-house technologies. The data used for this was primarily obtained from the websites of the firm. In a few cases, if no information was available online, the information included in their firm profile in the different BioPartner reports was used (BioPartner, 2003, 2004, 2005). This approach differs from the frequently applied method of patent counting and analysis, as was explained in the introduction.

To be able to take into account the temporal aspect of patterns of technology dynamics, we use the year of founding of the firms. The rationale for using this method of collecting data on technological focus at the time of founding is related to the specific characteristics of the population of firms we study. It has already been shown that in modern biotechnology, technological changes are primarily initiated by the entry of new firms, as opposed to shifts in the technological focus of already existing firms (Lemarié et al., 2000; Pyka and Saviotti, 2001). Moreover, the firms studied here are very young and small firms, each having their own highly specific knowledge on which their existence is based. These factors make it unlikely that their technological focus has already clearly switched to an entirely new focus since their foundation. We do acknowledge the possibility of there having been shifts in the technological focus of these firms, resulting in a more diversified technology portfolio. However, if such a shift has occurred, it is still expected that the core of this focus has remained similar. It is also more likely that they engage in related diversification, as opposed to unrelated diversification (Deephouse, 1999).

Beforehand, different technological fields were identified based on relevant literature, as has already been explained. The in-house technology portfolios of the firms were compiled at the end of 2005. The internet sites of the firms were studied separately by two researchers, who subsequently attributed the firms to their relevant technological field(s). To validate the results obtained, the two databases compiled in this way were compared and the differences were then identified, discussed, looked up again and decided upon. Working with the list of technological fields was an iterative process; as the different firms were examined for their technological focus, some categories were combined while others were added. This is considered to be relevant as the objective of this part of the study was to give an overview of technological developments in the Dutch life sciences.

2.3.3 Measurements

As has already been explained in Section 2.2, we measured the technological diversity of the annual populations of newly founded firms by taking into account the number of fields covered by these firms, and the standard deviation (SD) of the annual shares of these fields. The SD is used as it represents a standardised way of measuring the deviation from the mean annual share (Wonnacott and Wonnacott, 1990). The first step in determining this SD is to calculate the annual shares of each field, which are the number of firms founded on each specific field in a year divided by the total number of firms founded in a year. Subsequently, the standard deviation of these shares is calculated. Overall, the trend in the relative share of each field at t_n as compared to t_{n-1} combined with developments in the number of fields addressed determine whether patterns in technology dynamics converge, diverge, or remain stable. An overview of possible outcomes with regard to changes in technological diversity has already been given in Table 2.1.

In order to address the extent to which firms combine technological (sub)fields, we have also compiled a distribution based on the shares of firms focusing on a specific number of technological (sub)fields. These shares have been calculated by dividing the number of newly founded firms in a certain year that combine a specific number of technological (sub)fields by the total number of firms founded in that year. We make use of the skewness and kurtosis of the frequency distribution of the firms across the number of fields combined to assess whether this distribution deviates from that of a normally distributed random variable.

To be able to take into account explicitly the way in which technology dynamics at the level of the population are shaped by differences in the technology portfolios of newly founded firms over time, we used the network visualisation program NetDraw (Borgatti, 2002). The filled annual opportunity matrices (2000-2004) have been imported into this program, and firms combining knowledge of more than two technological fields have subsequently been added to the figures. Firms that were on the diagonal of the opportunity matrix in each year in each field were counted and the annual totals per field were imported into the figures as attributes of the fields, determining their relative size compared to the other fields in a particular year. This methodology is similar to the one used by Saviotti et al. (2005) for visualising the knowledge bases of firms using patents and their corresponding patent categories. In addition to the method of visualisation that was used by Saviotti et al. (2005), we are able to show individual firms within these figures. Furthermore, we are able to show firms working on one main field by adding their numbers as attributes of technological fields. There are no specialists as far as patents and their corresponding patent categories are concerned, since one patent is always attributed to more than one patent category given that they are designed to address different aspects of a single innovation.

The results will be discussed in the following section. We will start with the results we obtained concerning patterns of technology dynamics on the level of the population of firms, and subsequently focus on the role of individual firms in the developments of these patterns, using network visualisation.

2.4 Results

Table 2.3 provides an overview of the prominence of the different biotechnology-related technological fields in the Netherlands. This table provides results on 82 of the 93 firms that were originally studied here. This is due to the fact that the technology portfolios of the 11 remaining firms could not be evaluated because of, for instance, a lack of information in general, or lack of data on the specific technologies used by these firms. Also, the population of life sciences firms included some clinical research organisations, which will not be taken into account here as these organisations are purely service-oriented. It is important to note that a single firm could be attributed to more than one technological field.

Table 2.3 shows that the most prominent technological field is proteins and other molecules, within which protein engineering is an important area. Sequencing and synthesis of RNA/DNA as well as proteins and other molecules are also core fields. 22 firms are in some way involved in research and development in the field of instruments and devices, and 12 in bio assays. Another finding that can be derived from this table is the fact that no firms seemed to be working specifically on glycobiology. Thus, this field is apparently not an important focal point of R&D efforts of DDLSFs (yet). In the following sections, technological diversity of the population of newly founded firms will be examined further.

Table 2.3 Prominence of different biotechnology-related fields in the Netherlands

Technological field	No of firms active in the field
1. DNA/RNA	17, of which:
a) Gene probes, genetic engineering,	5
b) DNA/RNA sequencing/synthesis/amplification/purification	9
c) Functional and comparative genomics, structural genomics	4
d) Transgenic animals	0
e) DNA microarrays and oligonucleotide microarrays	6
f) Single Nucleotide Polymorphisms (SNPs)	1
g) Pharmacogenetics and pharmacogenomics: related to response to drug treatment	1
h) Oligonucleotides: short segments of DNA	2, of which:
I. Antisense technology/triplex technology	2
II. Aptamer technology	0
i) Ribozymes	0
2. Proteins and other molecules	39, of which:
a) Sequencing/synthesis of proteins and peptides	10
b) Protein isolation and purification	5
c) Protein engineering	18, of which:
I. Site-directed mutagenesis	2
II. Enzyme engineering	4
III. Fusion proteins	3
IV. Antibody engineering	8
d) Proteomics	4
e) Natural products	8
3. Cell and tissue culture and engineering	11, of which:
a) Cell/tissue culture, cell line development	2
b) Tissue engineering	1
c) Cellular fusion	0
d) Vaccine/immune stimulants	8
e) Embryo manipulation	0
4. Process biotechnology techniques	4
5. Gene and RNA vectors	2, of which:
a) Gene therapy	0
b) Viral vectors	0
c) DNA transfer	2
6. Bioinformatics/development of tools	23, of which:
a) Construction of databases on genomes	0
b) Modelling complex biological processes, including systems biology	0
c) Instruments, devices applied to biotech	22, of which:
I. Bioinformatics	2
II. High-throughput screening	6
III. Combinatorial chemistry	2
IV. Chiral chemistry	2
V. 3-D structures engineered proteins	4
7. Nanobiotechnology	1
8. Glycobiology	0
9. (Bio) materials	9
10. Bio Assays	12
11. Drug Targeting	9
Total number of firms	82 (out of 93)

2.4.1 Developments in the technological diversity of the population of newly founded firms

The following figures each provide information on the extent to which different technological fields are covered by the population of life sciences firms in 2004 according to their year of founding. As most main fields are only subdivided into a few subfields, limiting the variety within these main fields, we only present the results on all main categories (excluding Glycobiology as there are no firms working in this field) and the relatively refined DNA/RNA subfields. In each of the figures an additional line is included, which represents the total number of life sciences firms founded in that year. The scale of this line is presented as a secondary y-axis, on the right side of the figure, as it differs significantly from the scale of the primary y-axis. These figures provide information on the extent to which different technological fields are covered by new firms over time, and shifts in this coverage. The figures make it possible to evaluate whether the technological diversity of the population of newly founded firms has increased, decreased or remained stable over time.

As can be observed from Figure 2.2, the number of firms founded each year and included in this study first decreases between 2000 and 2002, and increases again thereafter.

From this figure, it can be derived that until 2004 the 'protein' field was relatively prominent compared to the other technological fields that were covered by newly founded firms. Also, in 2002 relatively many firms were founded working on bioinformatics and tools. In 2004, several fields have a similar share, and there does not appear to be a clear technological focus of newly founded firms in the Dutch life sciences[2].

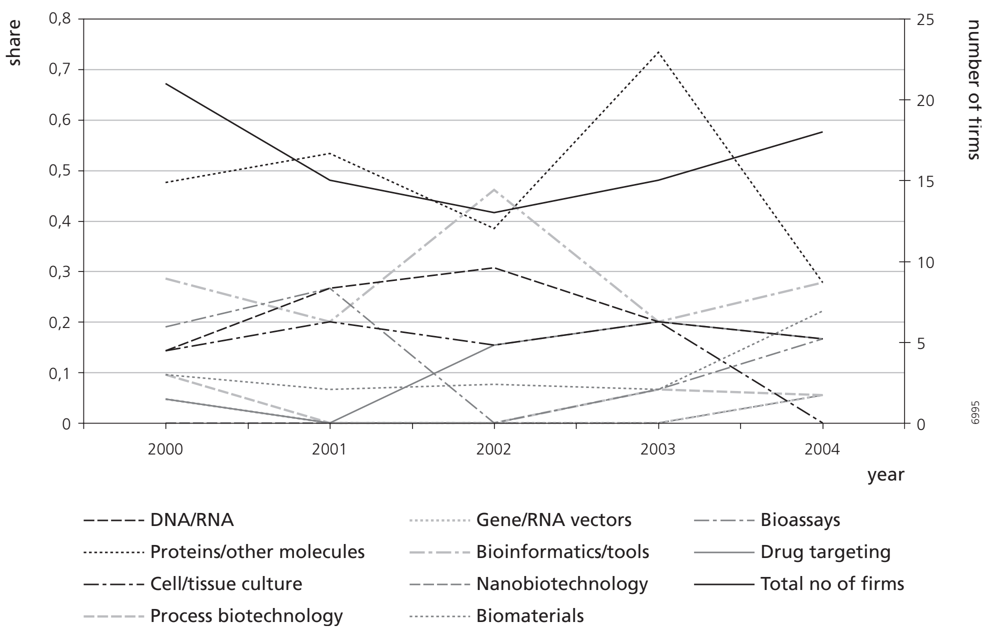

Figure 2.2 Annual shares of the different technological fields in the population of newly founded DDLSFs

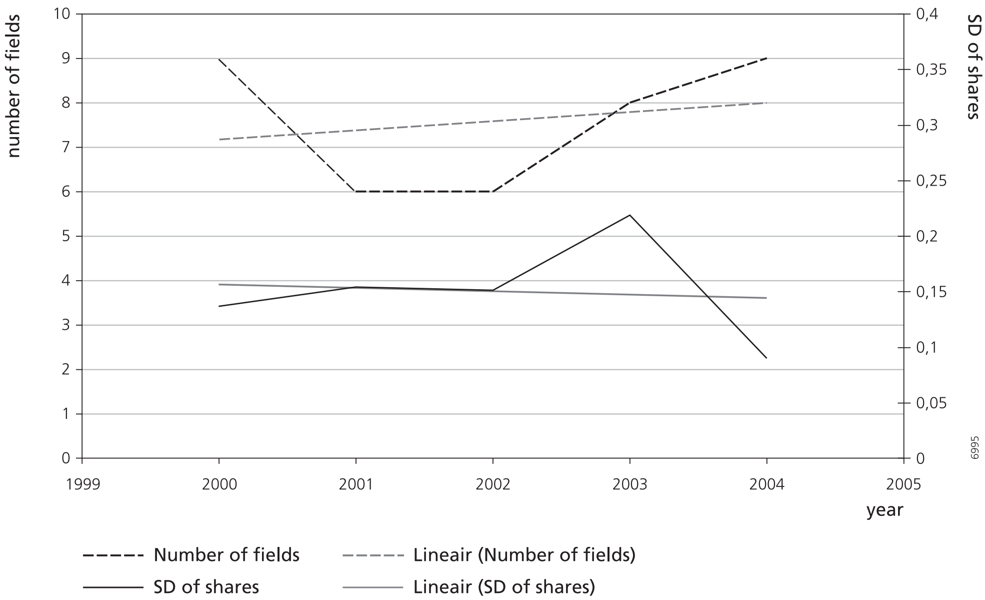

Figure 2.3 Technological diversity of newly founded DDLSFs: all main fields (1-11)

Figure 2.3 provides information on the development of technological diversity of the population of newly founded firms as measured by the number of technological fields and the SD of the annual shares of these technological fields over time. In order to gain an overall insight into the development of these two parameters, linear regression lines have been added to the figure.

Studying this figure in detail, it can be concluded that from 2000 to 2001 there is technological convergence, as during this period the number of technological fields addressed decreased while the SD of the shares of these fields increased. For the following year, 2001 to 2002, the number of fields addressed remained stable, while the SD of the shares decreased slightly. Combined, these developments indicate slight technological convergence. For 2002 to 2003 we are unable to determine whether the extent of population diversity increased or decreased, given that it is subjected to conflicting effects of the developments in the SD of the annual shares and the number of fields covered. From 2003 onwards, the number of technological fields increased, while the SD of the annual shares decreased, suggesting technological divergence.

The figure shows that developments in the number of fields covered, as well as the SD of the shares of these fields, were volatile from 2000 to 2004. Overall, with the increase of the number of firms founded each subsequent year, the number of different technological fields on which research and development activities are conducted also increased, but only slightly. Also, over time, the SD of the shares of these technological fields within the population of firms decreased slightly. These findings indicate that a higher number of different technological fields became covered by the population, and the different new firms founded became more equally distributed over these fields over time. This result thus signals that the variation in the focus of R&D efforts in the Dutch life sciences did not decrease over time, but rather increased slightly[3].

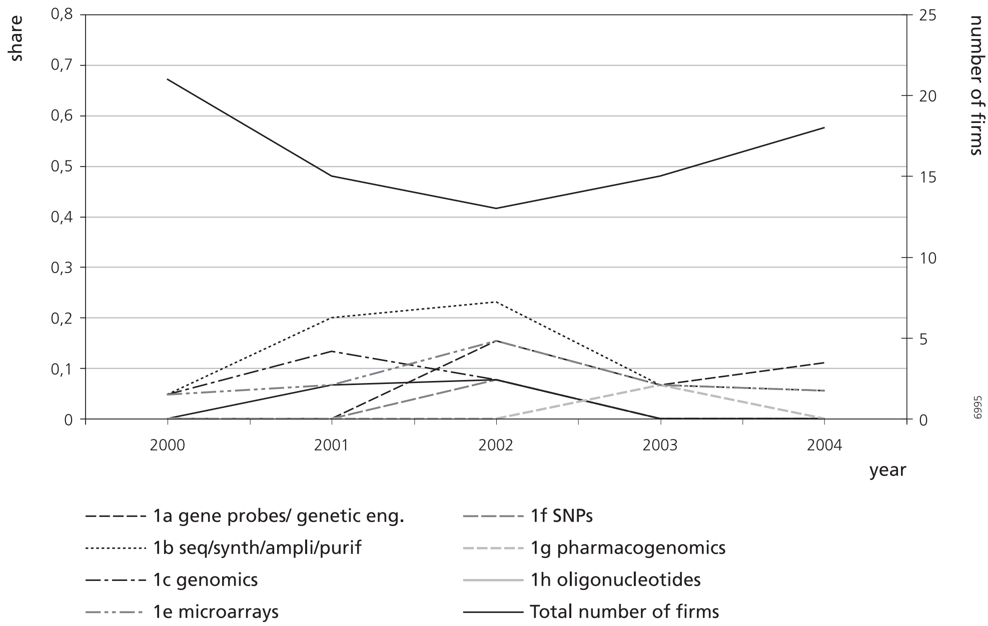

Figure 2.4 Annual shares of the different DNA/RNA-based fields in the population of newly founded DDLSFs over time

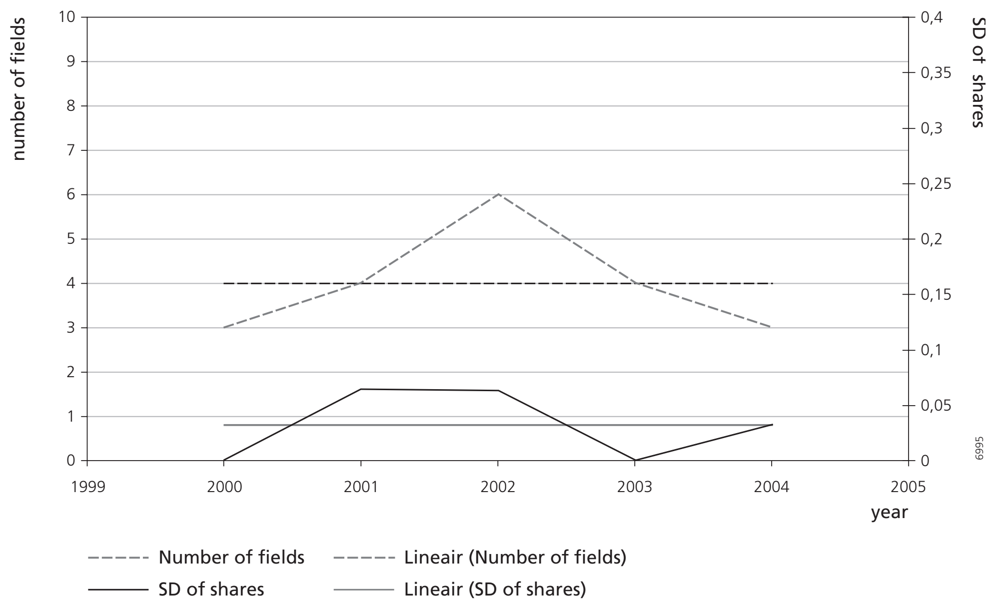

Figure 2.5 Technological diversity of newly founded DDLSFs: DNA/RNA-fields

Figure 2.4 provides an overview of the development of different DNA/RNA-related fields over time. From Figures 2.4 and 2.5 it can be derived that the number of technological subfields covered within the DNA/RNA main category fluctuates over time. This development in the number of subfields covered does not coincide with the developments in the total number of firms founded each year sequencing/synthesis of DNA/RNA was relatively prominent in the first years studied, but this prominence decreased over the last few years of the study. Developments in the shares of the different subfields have been somewhat similar since 2000, which is also reflected in the low SDs of the shares of these subfields. Looking more closely, it can be concluded that from 2000 to 2001 developments in the technological diversity were indeterminate. From 2001 to 2002 the technological diversity of the population increased. This was because the number of fields addressed increased while the SD of their annual shares remained stable. From 2002 to 2003 developments were again indeterminate. From 2003 to 2004 the number of fields addressed decreased while the SD of their annual shares increased, inidcating technological convergence. Overall, the technological diversity of newly founded firms in the field of DNA/RNA has been relatively stable, implying that patterns of technology dynamics neither converged nor diverged to a noticeable extent.

As has already been explained, Figures 2.2 to 2.5 provide information on developments regarding the prominence of different technological fields over time as the population of founded firms changes. Moreover, these figures have provided insight into the extent to which patterns of technology dynamics can be characterised as being convergent or divergent, or indeterminate. Overall, the results obtained on the main fields (Figure 2.3) reflect a slightly increasing rather than decreasing diversity within the populations of newly founded firms over time as there is an increase in the overall number of technological fields covered, while the SD of the annual shares of these fields declines slightly. Developments of the different technological subfields of the main field of DNA/RNA were relatively stable over time.

These patterns of technology dynamics are initiated at the level of the firm by new foundings in the different technological fields. We will address this issue in the following section.

2.4.2 Technology dynamics at the level of the firm

In this section we will present our results on technology dynamics at the level of the firm. As already explained, in Figures 2.2 and 2.4 one firm could be attributed to more than one technological field. Table 2.4 presents the frequency distribution of the number of technological subfields covered per firm. As can be observed from this table, many firms combine two or more technological subfields in conducting their R&D. Overall, 38 firms were attributed to one technological subfield only. Figure 2.6 provides an overview of the biotechnology-related technological fields these 38 Dutch firms are working in.

As can be concluded from Figure 2.6, bioinformatics and proteins and other molecules are the technological fields typically focused on by these firms. Within these two main categories, especially 6c (Instruments, devices applied to biotech) is dominant as all 12 bioinformatics firms specialise in this specific subfield. As was shown in Table 2.3, the number of different technological fields on which a firm conducts R&D differs from one firm to another. In order to see whether the distribution of firms across the number of subfields they combine is similar for firms founded in the different years under study here, Figure 2.7 visualises developments in the number of subfields covered by newly founded firms over time.

Table 2.4 Frequency distribution of the number of technological subfields per firm

No. of technological subfields	Frequency: No. of firms
1	38
2	29
3	8
4	5
5	1
6	1
Total	82

As can be derived from Figure 2.7, the share of specialist firms (only covering 1 subfield) is high in each of the five years. While in previous years there had also been considerable shares of firms combining two subfields, their share was low in 2004; below 0.2. Over time, there was a fluctuation in the share of firms working in one subfield only; this was the highest in 2004[4]. In 2004 the share of firms focusing on two subfields was low compared with previous years. The shares of firms working in three technological subfields or more were relatively stable over time.

We assessed the derivation of this distribution from a normally distributed random variable by examining its skewness and kurtosis. Overall, the skewness of the distribution of the firms founded from 2000 to 2004 across the number of combined subfields indicates a significant deviation from a normal distribution, in which a relatively large number of firms focuses on one or two technological subfields only (skewness = 1.580; $SD_{skewness}$ = 0.266). This is also the case for each of the annual distributions, except for that of 2003 which is not significantly skewed. Furthermore, the kurtosis of the overall distribution of firms founded from 2000 to 2004 across the number of subfields they combine is significantly positive, indicating a relatively sharp peak in this distribution (kurtosis = 2.847; $SD_{kurtosis}$ = 0.526). The annual distributions of 2000, 2001 and 2002 also show this significant deviation from a normal distribution, whereas this was not the case for the two remaining years, 2003 and 2004. Overall, these findings on the skewness and kurtosis of these distributions indicate that DDLSFs tend to be significantly technologically specialised.

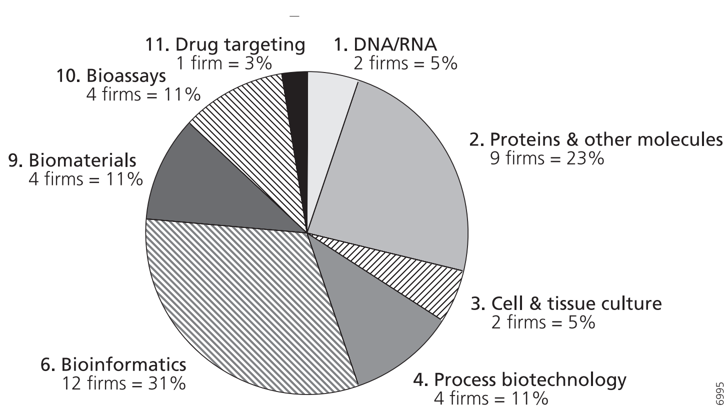

Figure 2.6 Distribution of technological fields for DDLSFs working on one biotech-related subfield (N=38)

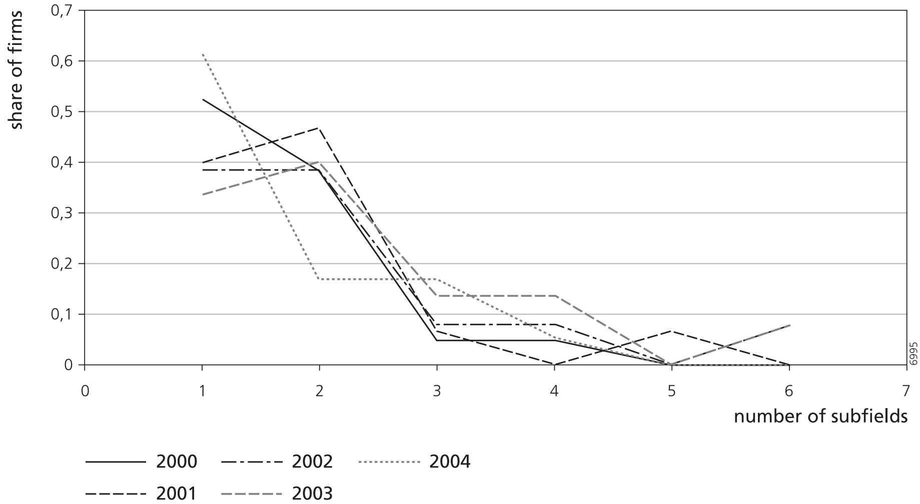

Figure 2.7 Developments in the shares of the number of subfields covered by DDLSFs over time

2.4.3 The network visualisation figures

In a further attempt to provide an answer to the third research question, this section addresses the extent to which knowledge related to the different technological fields specified is combined by newly founded DDLSFs. This enables us to assess the variety in combinations of different technological fields made by firms, and to relate this variety to the variety found among specialist firms as shown in Figure 2.6. An important question in this respect is whether the fields identified as 'specialist fields' in Figure 2.6 are also covered by firms that combine knowledge belonging to multiple technological fields, or whether these firms primarily focus on other fields.

As Table 2.3 shows, a large share of firms combine two or more technological subfields in their R&D. In order to gain insight into which fields are combined and how these combinations develop over time, we have compiled figures using the network visualisation program NetDraw (Borgatti, 2002). To enhance the clarity of these figures, the results on different subfields have been aggregated to the corresponding main field. Therefore, in these figures the nodes in the networks represent the main technological fields that were empirically identified in biotechnology (see Table 2.2). The data used to compile the figures are given in the Appendix belonging to this chapter.

The total number of firms founded in each year (N) is given directly below the figures. The relative size of each node in each figure was determined by the relative number of firms working only in that main technological field in a particular year. The numbers given inside the nodes represent the actual number of firms working only in this main field. This implies that firms attributed to a single node are either specialists or firms combining subfields of that main field. Field 8 (Glycobiology) has been omitted from the figures as none of the firms work in this field, neither specialists nor firms that combine this field with another field.

The smallest nodes in each figure indicate zero foundings in the corresponding field only in that year. Firms combining knowledge from different technological fields are represented by the lines connecting the nodes. A continuous line represents a firm that combines knowledge of the two main technological fields connected by the line. Dashed, dotted or other non-continuous lines represent firms combining knowledge of more than two main technological fields. Again, specific fields combined by a single firm are those fields connected by lines of a similar style. Based on this, these figures provide information on the development of the technological fields specified, and how these developments are induced by foundings of firms over time, thus from a micro-level perspective. They show how firms link different technological fields through their research and development. Some examples of the specific technological focus of firms combining knowledge of different fields will be given for each figure.

In 2000, 13 firms were founded that work in one main field only (as the number depicted in the nodes add up to 13). Most of these firms work in field 2 ('proteins and other molecules') or 6 ('instruments'). In total, 8 firms combine knowledge of more than one main field[5]. When examining firms combining knowledge of two or more technological fields, the prominence of field 2 is striking: 5 out of 8 firms that combine knowledge of different fields employ knowledge belonging to this technological field. Many combinations of different fields are made in 2000. For instance, one firm is engaged in the development of natural molecules, which includes assessing their biological activity using bioassays (combining fields 2 and 10). Another firm provides adjuvants (belonging to field 2) for vaccines (field 3).

The prominence of field 2 is also visible in Figure 2.9 which concerns firms founded in 2001 (N_{2001}=15). 4 out of 5 firms combining main fields work in this field, as well as 4 out of 10 firms

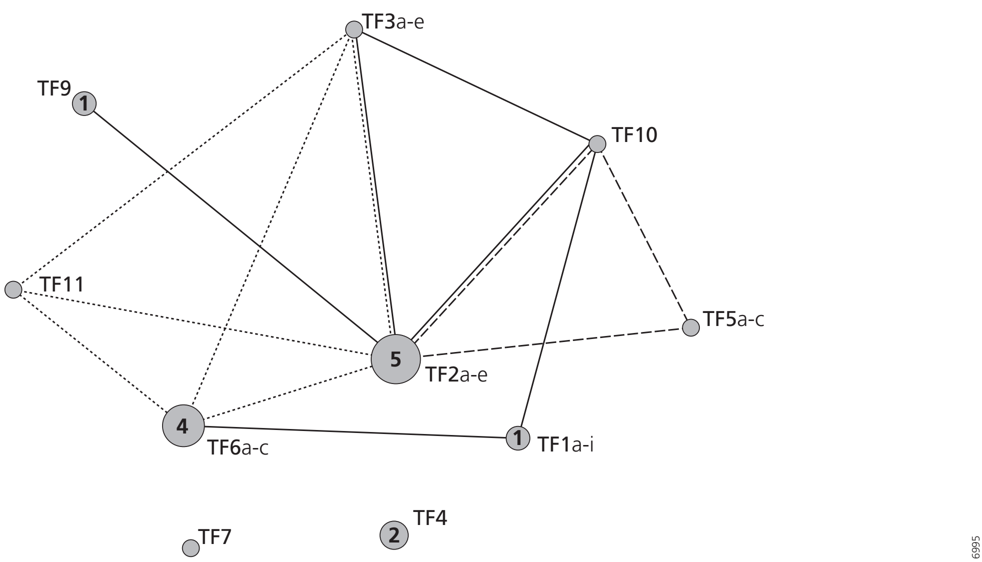

Figure 2.8 Technological fields (TFs) addressed by newly founded DDLSFs in 2000 (N_{2000} = 21; 13 working in one main field, 8 combining main fields); continuous lines each represent one firm combining knowledge of those main fields connected by this line; the sets of dashed and dotted lines each represent a firm combining knowledge of more than 2 main fields, also connected by these lines.

working in one specific main field. The number of different links made by firms between technological fields was lower in this year than in 2000, which can be ascribed to the lower number of foundings in 2001 than in 2000. For example, the firm founded in 2001 that includes fields 1, 2, 3 and 10 in its portfolio provides vaccine-related (clinical) services. These services include: bacterial genotyping (field 1) antigen purification (field 2), and providing diagnostic assays (field 10).

In 2002, the number of foundings decreases further to 13; these firms are almost equally divided between firms that work on one main field and firms that combine different fields (7 working on one main field, 6 firms combining main fields). As can be derived from Figure 2.10, technological field 2 remains prominent when the fields combined by firms are taken into consideration. However, there are few firms working only on this main field. In this year, field 6 attracts the most specialists and firms combining subfields belonging to the same main field. To illustrate: the firm combining fields 1 and 3 focuses on the inhibition of viral RNA. Both firms combining fields 2 and 11 are focused on the development of molecules with specific properties (field 2), directed at specific targets (field 11), or in specific formulations (field 11). One of these firms combines this knowledge with knowledge on chiral chemistry (belonging to field 6).

In 2003, field 2 was again the most prominent field, for specialists as well as for firms that combine fields. Relatively many firms founded in this year combined more than two main technological fields. All of these firms include field 2 ('proteins and other molecules') in their technology portfolio. The number of firms working in one main field only and those combining

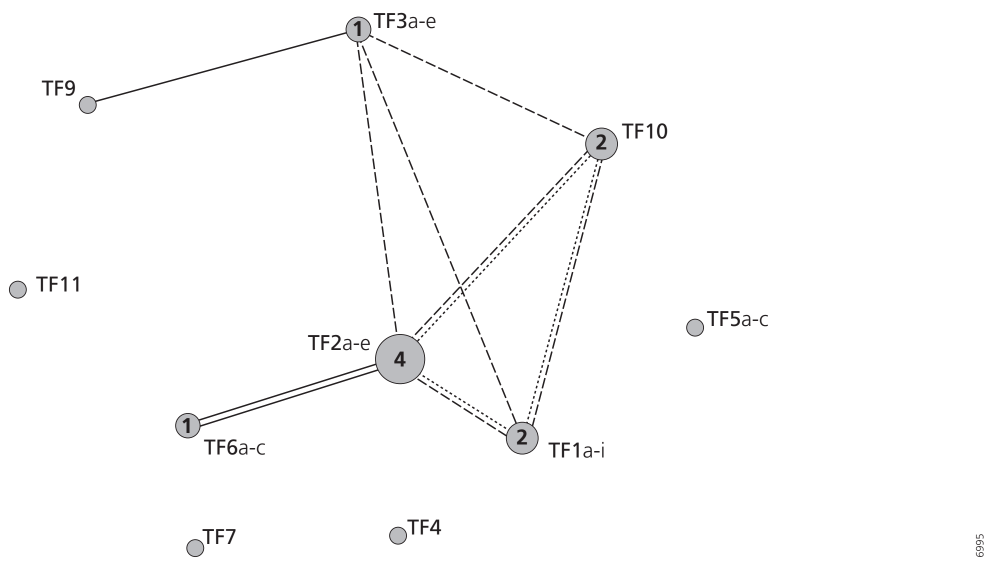

Figure 2.9 Technological fields addressed by newly founded DDLSFs in 2001 (N_{2001} = 15; 10 working in one main field, 5 combining main fields); continuous lines each represent one firm combining knowledge of those main fields connected by this line; the sets of dashed and dotted lines each represent a firm combining knowledge of more than 2 main fields, also connected by these lines.

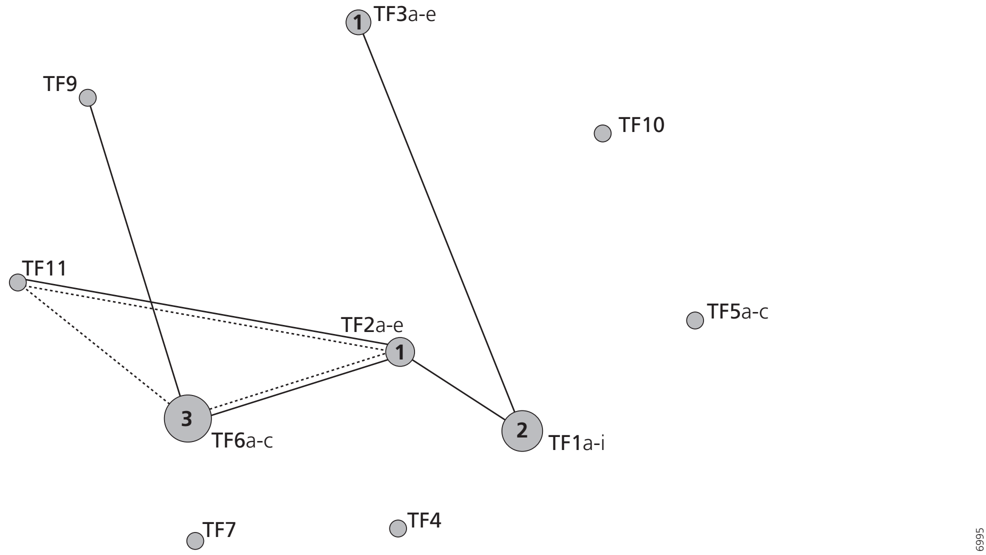

Figure 2.10 Technological fields addressed by newly founded DDLSFs in 2002 (N_{2002} = 13; 7 working on one main field, 6 combining main fields); continuous lines each represent one firm combining knowledge of those main fields connected by this line; the set of dotted lines represents a firm combining knowledge of more than 2 main fields, also connected by these lines.

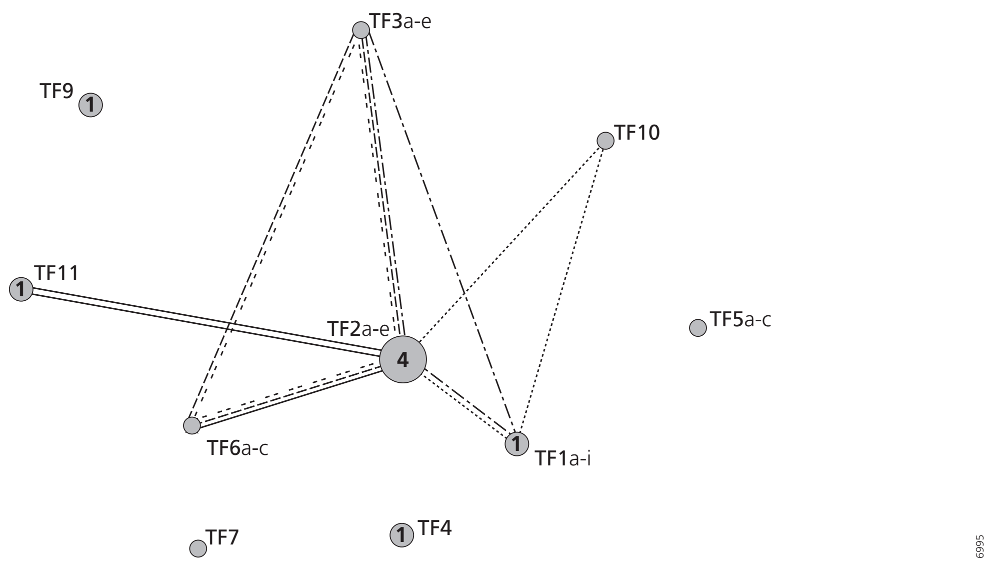

Figure 2.11 Technological fields addressed by newly founded DDLSFs in 2003 (N_{2003} = 15; 8 working in one main field, 7 combining main fields); continuous lines each represent one firm combining knowledge of those main fields connected by this line; other sets of similarly styled lines each represent a firm combining knowledge of more than 2 main fields, also connected by these lines.

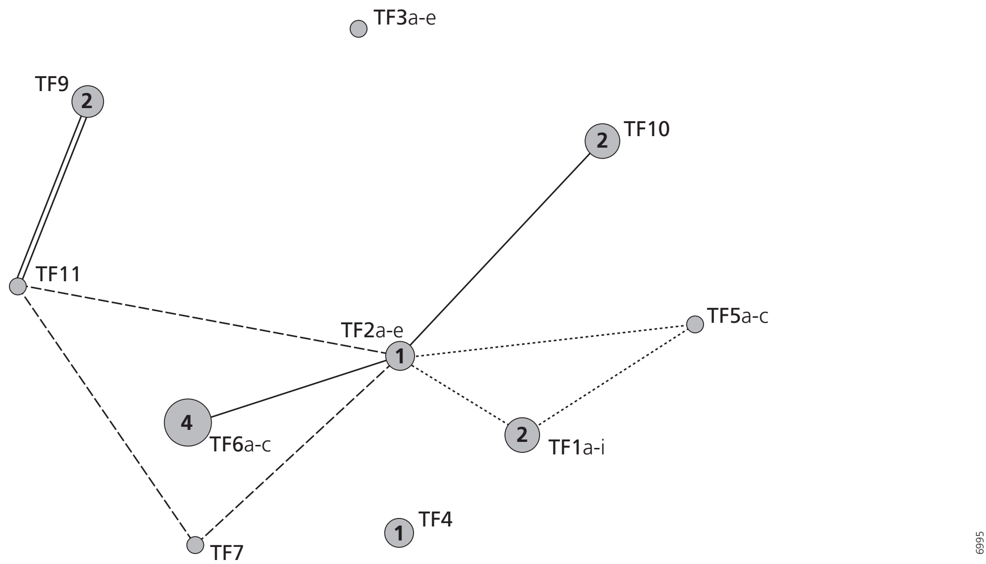

Figure 2.12 Technological fields addressed by newly founded DDLSFs in 2004 (N_{2004} = 18; 12 working in one main field, 6 combining main fields); continuous lines each represent one firm combining knowledge of those main fields connected by this line; the sets of dashed and dotted lines each represent a firm combining knowledge of more than 2 main fields, also connected by these lines.

fields was almost equal (8 working in one main field, 7 firms that combine main fields). In 2003 some of the combining firms employed knowledge of the same technological fields, which can be derived from Figure 2.11 from the fact that some pairs of fields are connected by several lines. For instance, two firms combine fields 2 and 11, working on formulations and targeted delivery of therapeutic molecules. Also, two firms combine fields 2, 3 and 6. Both firms aim at the identification (using field 6) and development of compounds (field 2) for the treatment of infectious diseases respectively allergies/autoimmune diseases (requiring knowledge of field 3).

In 2004, 12 firms focused on one main field, while 6 combined knowledge of two fields or more. Two of these firms that combine main fields focused on fields 9 ('biomaterials') and 11 ('drug targeting'). These firms are active in the development of drug delivery systems (field 11) using (biodegradable) implants (field 9). Furthermore, 2004 was the first year in which a new firm was established that incorporates nanobiotechnology in its technology portfolio. It is also the first year in which a firm made a direct connection between fields 1 and 5. This firm focuses on the development of gene (field 1) and protein (field 2) therapeutics, for which it uses DNA transfer (field 5).

2.4.4 Overall patterns of technology dynamics: relating the firm-level to the population level

Overall, Figures 2.8 to 2.12 show that 50 of the 82 firms are either specialists or combine knowledge of subfields that belong to the same main field as 50 firms work in one main field only (the numbers depicted in the nodes over time add up to 50). The 32 remaining firms combine knowledge belonging to at least two different main fields. Frequently occurring combinations of main fields include fields 2 (Proteins and other molecules) and 6 (Instruments and tools), 2 and 11 (Drug targeting) and 1 (DNA/RNA) and 2. Some other main fields, such as field 4 (Process Biotechnology), remain rather isolated, which is in line with results presented earlier in Figure 2.6.

In order to relate the findings presented in this section to the findings presented earlier on developments of the technological diversity, we here address the extent to which firms working in one main field and firms combining fields contribute to the total number of fields covered by firms annually. As is shown in Table 2.5, the number of different fields covered by specialists is relatively stable over time: 6 fields in 2004, 4 in 2002 and 5 in all other years. The number of fields addressed by firms combining fields founded in each year fluctuated from 8 in 2000 to 6 in 2001, 2002 and 2003, and 8 in 2004. As also already shown in Figure 2.3, the total number of different fields addressed each year was determined by the extent to which firms work in the same fields, information on which is provided in the fourth column.

As can be derived from the above table, in 2001 and 2002 firms working in one main field work in fields that are also already covered by firms combining fields, as the overlap in the fields of these firms equals the number of fields covered by firms working in a single field. Therefore, while the overall number of different fields covered in each year to a certain extent coincided with the number of firms founded in each year, additional variation is generated by the extent to which firms work on the same fields.

Table 2.3 shows that 'proteins and other molecules' is the most prominent field in the Dutch dedicated life sciences sector. From Figures 2.8 to 2.12 it can also be derived that this overall prominence is consequential to the fact that this field is prominent as far as firms working in one main field, as well as firms combining fields, are concerned. Based on the figures presented in this section, the decline detected in the prominence of field 2 in Figure 2.2 in the years 2002 and 2004 can be attributed to a decline in the number of firms working in this field in these years only relative to other years. In 2002 and 2004 only one firm focused solely on field 2.

Taking the network visualisation figures into account, it can be stated that the combinations of different fields made by firms over time are volatile. However, there does seem to be a dividing line between fields 6 and 11 on the one hand, and between 1, 5 and 10 on the other. Fields 2 and 3 are combined with fields of either of these two groups, but there are very few direct connections made by firms between the different fields belonging to both groups. Our results show that on the one hand, fields 6 and 11 are combined with 2 and 3 to identify, develop (and in some

Table 2.5 Contribution of DDLSFs working in one main field and firms combining main fields to the total number of fields covered in each year from 2000 to 2004

	No. of fields covered by DDLSFs working on one main field	**No. of fields covered by DDLSFs combining main fields**	**Overlap fields**	**Total no. of fields covered**
2000 (N = 21)	5 (n=13)	8 (n=8)	4	9
2001 (N = 15)	5 (n=10)	6 (n=5)	5	6
2002 (N = 13)	4 (n=7)	6 (n=6)	4	6
2003 (N = 15)	5 (n=8)	6 (n=7)	3	8
2004 (N = 18)	6 (n=12)	8 (n=6)	5	9

cases administer to patients) molecules with certain characteristics, whereas fields 1, 5 and 10 are combined with fields 2 and 3 in order to enable the development of all sorts of analyses and diagnostics, including analysing the genetic composition of organisms. Firms working on the use of DNA or RNA for disease treatment purposes represent an exception to this general tendency. An example of such a firm is the firm that combined fields 1 and 3 in 2002, which focuses on the use of RNA inhibition in the development of therapeutics. The division of biotechnology fields into these groups of fields did not change over time. There would seem to be new areas of application arising over time. For instance, new opportunities arising from developments in the fields of nanobiotechnology have led to the founding of a firm in 2004 that combines knowledge from the nanobiotechnology field with the delivery of therapeutics.

2.5 Discussion

This chapter aims to provide insight into a conceptualisation of the technology dynamics of emerging technologies. This conceptualisation was applied in this chapter to the case of Dutch biotechnology in which we focused on patterns of technology dynamics as induced by newly founded DDLSFs. Due to the low number of empirical studies on technology dynamics, especially those not making use of patent data, it is difficult to compare our findings to other findings on this topic. However, our finding that the annual populations of newly founded firms show an increasing level of technological diversity is in line with notions derived from population ecology that emphasise variation among firms in technological fields in a nascent stage of development (Brittain and Freeman, 1980). Apparently, forces that increase variation prevail over those of imitation as patterns of technology dynamics induced by newly founded firms show an increasing level of diversity of subsequent populations of newly founded firms

Moreover, the results show that most of the firms studied are specialists, and that this applies with regard to the firms founded in the different years studied. This finding is also in line with the notion of Brittain and Freeman (1980) and Baum and Rao (2004) deriving from population ecology that the emergence of new technological fields encourages the founding of specialists, that explore new technological opportunities embedded in specific technological niches. It is also in line with the findings of Orsenigo et al. (2001) who signal the emergence of specialist organisations in newly uncovered technological fields.

In addition to these specialists some technological subfields were frequently found to be combined by DDLSFs, for instance the subfields of fields 2 (Proteins and other molecules) and 10 (Bioassays). This could be explained by the fact that these fields are closely linked together in the scientific sense. The emergence of new screening technologies has resulted in 'newer' bioassays techniques complementing the older technological field of antibody synthesis and engineering. In this respect, these technological fields should be seen as fields that complement one another rather than compete against one another; this is indicative of the systemic nature of the technological fields studied here (Barnett, 1990).

Although field 2 (Proteins and other molecules) was shown to be prominent, results on technological kernels are volatile; there are fluctuations over time. There does not seem to be a single most prominent field in Dutch biotechnology. The question then arises to what extent some kind of convergence of research efforts in biotechnology in the Netherlands would be needed to increase the chances of survival of these firms. However, prior research on populations of biotechnology firms in France, Germany and the UK also notes the absence of specialisation among these firms on a national level (Lemarié et al., 2000).

The main contribution of this study is embedded in the conceptualisation of patterns of technology dynamics. On the one hand, we made use of the concepts of technological convergence and technological divergence on the level of subsequent populations of newly founded firms. By assessing both the number of fields covered by these populations of firms over time, and the relative importance of these fields, we have been able to provide insight into the development of an emerging technology over time. On the other hand, we have also introduced the so-called opportunity matrix to gain insight into technology dynamics at the level of the individual firm. Furthermore, in order to visualise these dynamics we applied network visualisation, which turned out to be a very useful tool in analysing these patterns of technology dynamics generated by other populations of firms working in biotechnology, as well as populations of firms working in other technological fields that are in a nascent stage of development.

2.6 Conclusion

Returning to the central question of this chapter, namely: "*How can patterns of technology dynamics of emerging technologies be conceptualised in general?*" And more specifically to the Dutch biotech case: *"Which patterns of technology dynamics could be discerned at Dutch dedicated life sciences firms, newly founded in the period 2000-2004?"* it can be concluded that the concept of technological diversity as applied in this study provides useful insights into the technological developments initiated by subsequent populations of Dutch dedicated life sciences firms over time. On the level of the individual newly founded firm, the notion of an 'opportunity matrix' of technology development combined with network visualisation provides insights into technology development. The conclusions with regard to the more specific research questions (1 to 3) that can be drawn from the findings obtained are elaborated on below.

To answer the first research question, namely "*Which technological fields can be discerned in modern biotechnology, and how can they be classified?*" we conducted a literature search for relevant technological (sub)fields. This resulted in a list consisting of 11 technological main fields, most of which were further specified into multiple subfields.

Overall, Dutch policies aiming to stimulate the founding of life sciences firms, the most important of which was the establishment of the BioPartner Network programme, have not triggered focus in the R&D efforts of these newly founded firms. Rather, in an attempt to answer the second research question, namely "*What patterns in the development of the technological diversity of the population of newly founded firms could be discerned for subsequent annual populations of these newly founded firms?*" we found an increase in the number of technological fields covered by the newly founded firms and, in addition, the research efforts of firms have become more equally divided over these fields. These two tendencies indicate an increasing technological diversity of the annual population of newly founded firms over time. Further research addressing technology dynamics in the Dutch life sciences over a longer time span would give insight into developments in technological diversity in the long run, and enable us to address the significance of these developments.

Finally, with regard to the third research question, i.e. "*To what extent are Dutch dedicated life sciences firms newly founded in the period 2000-2004 specialists, focusing on one specific technological (sub)field, and to what extent do they combine various technological fields?*" it can be stated that a relatively high share of firms (38/82) focus on one technological subfield only. These firms are thus specialists. Furthermore, 12 firms combined two or more subfields belonging to the same main technological field. Also, some combinations of main fields made by firms were frequently observed. For instance, many firms combined subfields of fields 2 (Proteins and other molecules) and 10 (Bioassays).

Overall, Dutch life sciences firms have been active in the following kernels of technological fields: sequencing and synthesis of DNA/RNA as well as proteins and other molecules, protein engineering, instruments and tools, and bioassays. The prominence of these fields results from a large number of specialists as well as from firms combining these fields over time. While these fields attract specialists as well as firms combining fields, field 4 ('process biotechnology') only attracts specialists and is not combined with other main fields.

While the approach that was followed provided useful insights into the technology dynamics of an emerging technology it also has some limitations that need to be taken into consideration when conducting further research. First of all, the method used to collect the data, namely information obtained from the websites of the firms studied, could result in biases in the results obtained. For instance, firms might be reticent to put complete information on the technological fields they are working on online. Also, possible use of fashion wording could contaminate the results obtained. A further refinement of the research methods used here to study technology dynamics of an emerging technology could be made by introducing more elaborate methods of data collection, for instance case study research based on in-depth interviews, in order to unravel the precise technological fields firms are working in. Also, event-analyses, in which specific events are studied over time could contribute to more in-depth knowledge of technology dynamics and possibly also of rationales driving decisions concerning these dynamics over time. This would give greater insight into the precise mechanisms of technology diversification over time, and thereby contribute to research into technology dynamics.

Secondly, because the year of founding was used as the temporal dimension of technology dynamics, we were unable to trace the technological diversification of individual firms over time. By making use of the other data collection methods proposed above it would be possible to gain insight into this diversification. Additionally, focusing on the year of founding might also provide biased results. There might be a discrepancy between the technological focus at the year of founding and the technological fields they are working in in 2005. However, since we have restricted our sample to firms that have been founded since 2000 we have been able to limit this discrepancy, assuming that firms will stay in a particular technological field for at least a few years.

This research showed that using the opportunity matrix concept in combination with network visualisation methods to visualise technology dynamics is a useful tool to give initial insights into technology dynamics of emerging technologies. Further research could focus on elaborating this tool and coupling it with traditional Variation, Selection, Retention models, if possible, for emerging technological fields, such as modern biotechnology.

3 Development of structure in the emerging network of collaborative relations of Dutch dedicated life sciences firms from 2002 to 2004

3.1 Introduction

During recent decades many studies on firm behaviour and industry development have used a science-based industry as their main empirical setting, some comparing characteristics of science-based industries to less knowledge intensive industries (Hagedoorn, 1993; Hagedoorn and Narula, 1996; Meyer-Krahmer and Schmoch, 1998; Gulati and Gargiulo, 1999). These efforts of researchers to gain insight into science-based industries are related to the expected economic potential of these industries within individual countries and economies. Stimulating different science-based sectors is thought to contribute to the foundation of a so-called knowledge-based economy (Ministry of Economic Affairs, 2003). Public authorities operating at different levels of policy making, European as well as national and regional, have developed initiatives aimed at supporting entrepreneurial activity in science-based industries. One of the results of these policies is the increasing number of incubators that have been established to support entrepreneurial activity and stimulate the formation of clusters of science-based activities (Phan et al., 2005). Specific attention given to the establishment of clusters of activity is inherently driven by the characteristics of science-based industries. Due to the speed of technological change it is impossible for individual organisations operating in a science-based industry to possess all the capabilities and resources required for in-house research and development activities. This results in a certain distribution of competences and resources across actors that are active in an industry (Meyer-Krahmer and Schmoch, 1998; Pyka and Saviotti, 2001). This distribution of competences and resources makes it imperative for organisations to search for partners in order for them to make use of those assets of those partners that are complementary to their own (Pfeffer and Salancik, 1978). The notion of a certain liability of unconnectedness, for instance in modern biotechnology, provides a distinct indication that establishing partnerships is indeed a necessary condition for firm survival and growth (Powell et al., 1996). In view of this, the formation of networks of collaborative activities in new science-based industries is considered to be pivotal for the survival and growth of these industries.

While several studies have examined the evolution of individual interorganisational relations (Doz, 1996; Arino and De la Torre, 1998; Van de Ven et al., 1999; Reuer et al., 2002) very little is known as yet about the emergence of networks in science-based industries and their development over time. Recently, some studies have addressed these issues by examining publicly announced, newly established collaborative agreements between organisations engaged in modern biotechnology and the life sciences (Owen-Smith and Powell, 2004; Gay and Dousset, 2005; Powell et al., 2005; Roijakkers and Hagedoorn, 2006). In some studies, the boundaries of the collaboration network have been defined on the basis of geographical location of the organisations involved (Owen-Smith and Powell (2004)), while others have further specified the network according to technology-based characteristics of the collaborative agreements of the organisations involved (Gay and Dousset (2005)). However, such data provide a biased view on the network of collaboration among organisations and its development over time in at least two ways. First of all, only those collaborative agreements that are publicly announced are taken into account. It is questionable whether the visible and examined tip of the iceberg is representative of the majority of the iceberg beneath the surface (Powell et al., 1996). This also implies that the size of the collaboration network of organisations engaged in modern biotechnology and the life sciences remains unknown. Consequently, formal contractual agreements are focused on, while informal agreements are not taken into account. Additionally, organisations that are not involved in collaboration are left undetected and therefore not included in the research population. This implies that no attention is paid to the extent to which firms and other organisations do *not* engage in collaborative activities. Secondly, the emphasis is on the *formation* of collaborative relations, not on *involvement* in collaboration and its duration. This bias is caused by the focus on newly formed alliances through the use of their public announcements. In most studies, the continuation and discontinuation of collaborative agreements are not taken into account. This raises the question whether the dynamics of networks found in these studies differ from the actual dynamics of collaboration between organisations that shape the network. Powell et al. (2005) have provided some initial insights into the volatility of the network comprised of dedicated biotechnology firms and their partners, focusing mostly on US firms.

In this study, the development of the Dutch life sciences industry is examined. More specifically, the development of the network of collaborative relations of the population of Dutch dedicated life sciences firms (DDLSFs) over time will be analysed using survey data. This implies that an emerging network is studied. Other types of organisations are also taken into account in this study, but only as partners of the dedicated life sciences firms. Knowledge of the size of the population and thereby of the boundaries of the network studied enables us to provide insight into the development of this network, and thus into the development of the life sciences industry within the Netherlands. The method of data collection used makes it possible to take into account formal as well as informal collaborations, which are considered to be pivotal in this study of network emergence. Also, given that the sample is not restricted to newly formed relationships only, the continuation of collaborative relations over time will also be addressed. Moreover, insight into the extent to which firms actually do *not* collaborate can be obtained. When it comes to non-response to the surveys, the missing data are known as the research population has been defined. Consequently, the following research question will be addressed:

To what extent and in what way did the network of interorganisational collaborations of Dutch dedicated life sciences firms emerge and develop from 2002 to 2004?

While analysing network dynamics from 2002 to 2004 represents a relatively limited time span compared with other studies on network dynamics (such as Gay and Dousset (2005), Powell et al. (2005), covering the periods from 1987 to 2004 and 1988 to 1999 respectively), many Dutch dedicated life sciences firms have been founded only since 2000. Studying the collaborative relations of these firms from 2002 to 2004 therefore provides insight into the emergence of the network.

In order to address this question, a theoretical framework based on insights into collaboration networks of life sciences firms is derived in order to formulate related conjectures (Vanhaverbeke and Noorderhaven, 2001). In order to examine these conjectures, the emerging network of collaborations of Dutch life sciences firms will be described and the data on this network development will be analysed. For this analysis, a graph-theoretical approach will be taken and complemented with the use of some methods derived from network analysis. A discussion of the research conducted and conclusions drawn from the results will be presented in the last section of this chapter.

3.2 Theoretical considerations

The emergence of high technology industries has caused consistent growth in the number of newly formed R&D collaborations between firms since the 1960s (Hagedoorn, 2002). Roijakkers and Hagedoorn (2006) provide an overview of developments in the number of newly formed collaborative agreements between firms in pharmaceutical biotechnology. They also find a general pattern of growth in the number of agreements. Among other things, the increasing amount of flexibility that is required by firms engaging in collaboration in high technology sectors has led to an increasing prevalence of relatively short-term, contractual and thus non-equity-based relationships at the expense of equity-based relationships such as joint ventures (Hagedoorn, 2002; Roijakkers and Hagedoorn, 2006). On the macro-level, these micro-level developments generate dynamics in the collaboration network.

Several studies have examined the formation and development of networks in the life sciences and biotechnology. Most of these studies covered collaborative behaviour from the 1980s until now. Owen-Smith and Powell (2004) studied interorganisational networks in biotechnology in the Boston region. Their results indicate the important role of public research institutes within the emerging local network. Over time, the importance of these institutes decreases, while the role of established firms grows. Direct interfirm collaborations gain importance, and the role of research institutes as hubs in the network is reduced. The important role of research institutes within an emerging network was also proposed by Kogut (2000), signalling the importance of research institutes in science-based sectors. Gay and Dousset (2005), who studied collaboration in a specific technological segment of biotechnology, found that interfirm collaborations are dominant. Their emerging network is dominated by collaborations between biotechnology firms and established pharmaceutical firms, and over time collaborations between biotechnology firms gain importance. Powell et al. (2005) found that research institutes are pivotal nodes in the emerging network of life sciences collaborations, together with some biotechnology firms and some large multinational firms. Over time, as commercialisation strategies and financing become more important, the providers of venture capital gain central positions in the network. Along with an increasing diversity of types of organisations active in the network, there is also a shift in the characteristics of the most central nodes. Over time, however, a few research institutes do remain among the most important actors. Next to the increasing diversity of organisations, there is also an increasing diversity of types of linkages within the network.

In the study on interfirm collaborations in medical biotechnology by Roijakkers and Hagedoorn (2006), established firms were the hubs in the emerging network. Over time, biotechnology firms started to fill bridging positions in the network. While established pharmaceutical firms remained important within the network when the node degrees of individual organisations are taken into account, their centrality in the network did fluctuate. Over time, the importance of these established firms increased again, while the extent to which biotechnology firms filled bridging positions decreased (Roijakkers and Hagedoorn, 2006). It is however difficult to compare this study with most of the studies discussed above given that it is focused on interfirm collaborations only, and thus disregards the position of research institutes within interorganisational networks.

In their theoretical model of network development Gulati and Gargiulo (1999) make a distinction between exogenous and endogenous causal factors. In the initial stages of network emergence, the resources and competences of different actors determine the positions of these actors in the network (Gulati and Gargiulo, 1999). Their results indicate a growing importance of endogenous factors over time, implying that the past structure of an interorganisational network influences the current structure of this network. They found confirmation for effects along three lines, namely by examining the number of prior alliances between two organisations, the number of prior indirect alliances between two organisations (common third parties) and the value of the combined network centrality of two organisations. The effects of these variables on the probability of the formation of a new alliance between two organisations were found to be positive.

Structural differentiation was shown to be a mitigating factor determining the influence of these endogenous factors. Once some kind of structure has emerged, that structure, and the positions of individual firms within it begins to exert an influence on the subsequent development of the network as well. The extent to which structural differentiation occurs is related to the extent to which certain organisations in the network have the opportunity to occupy more central positions by engaging in relatively many collaborations. This in turn depends on the distribution of resources across the population of organisations, and the extent to which some organisations have significantly better resource portfolios than the majority of the organisations in the population (Gulati and Gargiulo, 1999; Soh and Roberts, 2003). This mitigating effect of structural differentiation is closely related to analyses of power law distributions that have been conducted in some studies. Over time, preferential attachment, i.e. the notion that new organisations preferably attach to already well-connected organisations (Barabási and Albert, 1999), is proposed to have a significant influence on the structure of the network. In view of this, several studies have devoted attention to the development of the distribution of degrees of nodes over time (by examining power law distributions). However, in two recent studies of network development in the life sciences no evidence was found of actual preferential attachment as defined by Barabási and Albert (1999) (Gay and Dousset, 2005; Powell et al., 2005). One reason given by Gay and Dousset (2005) for this result is that the technological specificity of partnering and the pace of technology succession and differentiation circumvent preferential attachment of all actors to only a few centrally positioned ones. However, hubs do exist in these networks.

Overall, it can be concluded that these studies provide insight into some general trends in network emergence and development. First of all, emerging networks are characterised by collaborations between established organisations (research institutes or firms) and new technology-based firms. These established organisations represent the hubs in the network, while dedicated technology-based firms act as bridges between these hubs. While the notion of small-world networks developed by Watts and Strogatz (1998) does account for these bridging positions, it does not account for the emergence of hubs within a network, nor does the notion of random networks (Powell et al., 2005). Studies have therefore referred to preferential attachment to explain the existence of these hubs (Barabási and Albert, 1999). Secondly, the importance of collaborations between dedicated technology-based firms increases over time, but in most cases established organisations remain dominant hubs in the network. The results of some studies show a shift from a dominance of established research institutes toward a dominance of established firms (Owen-Smith and Powell, 2004). Furthermore, endogenous network mechanisms leading to some, but not necessarily complete, preferential attachment seem to be active (fitter get fitter; fitter get richer, in terms of connectedness to other organisations). Over time, the interorganisational network evolves from being dispersed to being more connected. While the firms that constitute the network primarily focus on conducting R&D, over time market-related activities (like production and marketing) will also become part of the network. However, due to the science-based character of the industry, interorganisational R&D activities remain important.

Whereas Roijakkers and Hagedoorn (2006) and Gay and Dousset (2005) examined network development over a lengthy time span, the Boston network studied by Owen-Smith and Powell (2004) mainly focused on network emergence. The focus of this study is also on this emergence as most DDLSFs have only been established since 2000.

The following conjectures (Vanhaverbeke and Noorderhaven, 2001) are derived from the findings reported above:

1. The collaboration network of DDLSFs will initially be fragmented.
2. The number of nodes will increase over time, as will the number of linkages between the nodes.
3. Established research institutes will be dominant hubs in earlier phases of network development.
4. The importance of established firms in the network will increase over time.
5. The number of non-collaborators will be small and will diminish over time.
6. Over time, the network of collaboration will become more structured, increasing the importance of endogenous network effects.

In the following section, we will discuss the data analysis and results that address these conjectures.

3.3 Network data analysis and results

3.3.1 Data collection

In 2000, the Dutch Ministry of Economic Affairs started the BioPartner Network programme. The central aim of the BioPartner Network programme was to stimulate entrepreneurship in the Dutch life sciences industry; the target was to support the establishment of at least 75 firms over a period of five years. In this respect the BioPartner Network acted, among other things, as a public seed capital provider. In order to monitor the development of the Dutch life sciences industry (which is seen as an important sector for the development of a knowledge-based economy and future economic growth in the Netherlands) a registration of DDLSFs was set up in 2000 based on the records of the Dutch Chamber of Commerce. Since 2002 this registration is accompanied by a survey which is distributed among the CEOs of DDLSFs. Apart from various questions on organisation and business development indicators, the survey also contains a name generation question inquiring about the five most important partner organisations and additional questions about some basic characteristics of the collaborative relations with these partner organisations. The latter questions concern the nature of the collaboration (R&D, marketing and sales, distributions, production) and, since 2004, the way the collaboration is organised (joint R&D, joint venture, licensing, R&D outsourcing, R&D financing). The data collected on collaborative relations of DDLSFs concern not only other dedicated life sciences firms but also other types of organisations such as research institutes and established firms.

At the end of 2002 and 2004 the population of DDLSFs consisted of 126 and 157 firms, respectively. During the years 2003 and 2004, 19 firms left the population due to discontinuation of their business activities (10) and mergers and acquisitions and relocating abroad (9). New entrants during these years comprised 39 firms. Furthermore, 11 firms changed their business activities towards the life sciences before the end of 2004 thereby qualifying themselves for registration and increasing the population of DDLSFs to 157 at the end of 2004. This implies that 107 firms already established in 2002 (85%) were also part of the population in 2004 (73%). New entrants comprised 25% of the 2004 population while 15% of the 2002 population had left before the end of 2004.

The surveys held in 2002 and 2004 had response rates of 87% and 69%, respectively. The network data used here were derived from a name generation question included in this survey on the five most important partners of the DDLSF. Of the 110 returned questionnaires in 2002, 63 contained the names of the most important partner organisations. Seven firms indicated not to be involved in a collaborative relation with another organisation (6%). Of these non-collaborating firms in 2002 only 2 responded the same in 2004, 3 were involved in collaboration in 2004 and 2 did not respond to the survey in 2004. The 2004 survey provided 108 returned questionnaires of which 74 contained the names of the most important partner organisations and 12 indicated that the firms were not involved in collaboration with another organisation (11%). In 2002 57% and in 2004 68% of the firms responding to the surveys stated to be involved in collaboration with other organisations; i.e. a growth of 5% per year.

The 63 responding firms in 2002 were involved in 187 collaborative relations of whom 35 still existed in 2004. Given that 24 of the 63 responding firms in 2002, with 67 collaborative relations in 2002, still existed in 2004 but did not answer the name generation question on partner organisations in the 2004 survey, the percentage of continued collaborative relations becomes 29.2% ([35/(187-67)]*100%)[6]. The 74 responding firms in 2004 were involved in 192 collaborative relations. So, over two years of observation the pace of expansion of the collaborative network of DDLSFs was 1.3% per year.

In order to estimate the degree to which the sample data on the five most important partners mentioned by the DDLSFs responding to the surveys are representative of all collaborative relations of all DDLSFs in 2002 and 2004, data obtained from another question in the surveys on the total number of partnerships of each DDLSF with other organisations were used. The representativeness of each sample of collaborative relations, which is called its reliability, can be estimated by applying two-stage sampling methods (Moors and Muilwijk, 1975), the first stage being the representativeness of the sample of respondents, and the second stage being the representativeness of the sample of partners specified by each respondent. The sample data on collaborative relations of DDLSFs have an estimated reliability of 85% for 2002 and 86% for 2004 (employing a 95% confidence interval). As the surveys only contained the names of partners and no data on other characteristics of these organisations, selectivity in the response of the DDLSFs in both samples, potentially violating the assumptions of random samples, cannot be assessed. Furthermore, in the networks studied here, relations between DDLSFs and their partners, as mentioned in the name generation question, are considered to be dyadic, implying that we cannot determine if relations were part of partnerships with more than one partner. Also, multiple relationships of DDLSFs with the same other partner(s) cannot be discerned. The high reliability of the samples of relationships in 2002 and 2004 must thus be considered with these limitations in mind. In other empirical studies on interorganisational networks, information on the reliability has not been reported as most of them use data derived from public announcements of collaborative relations. Neither information on the population of organisations referred to nor their total number of partnerships are included in such data, which makes it impossible to estimate the reliability of the network data analysed.

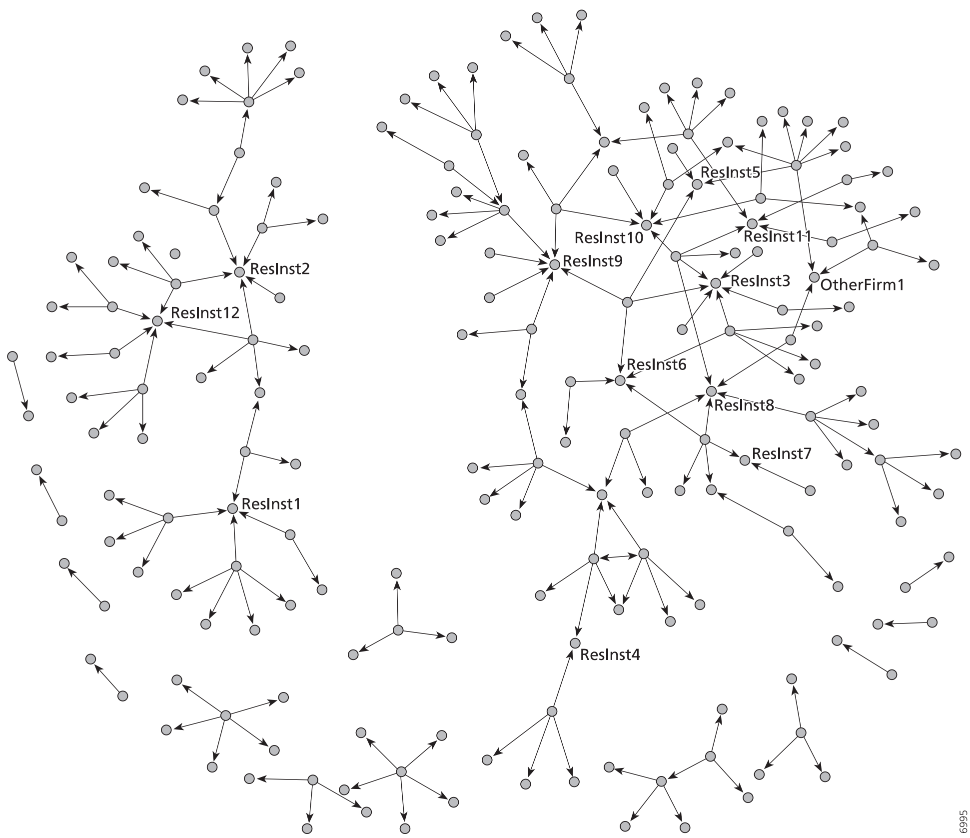

Figure 3.1 Network of collaboration of DDLSFs in 2002; The hubs in the network are labelled: ResInst = research institute; other firm = non-DDLSF firm

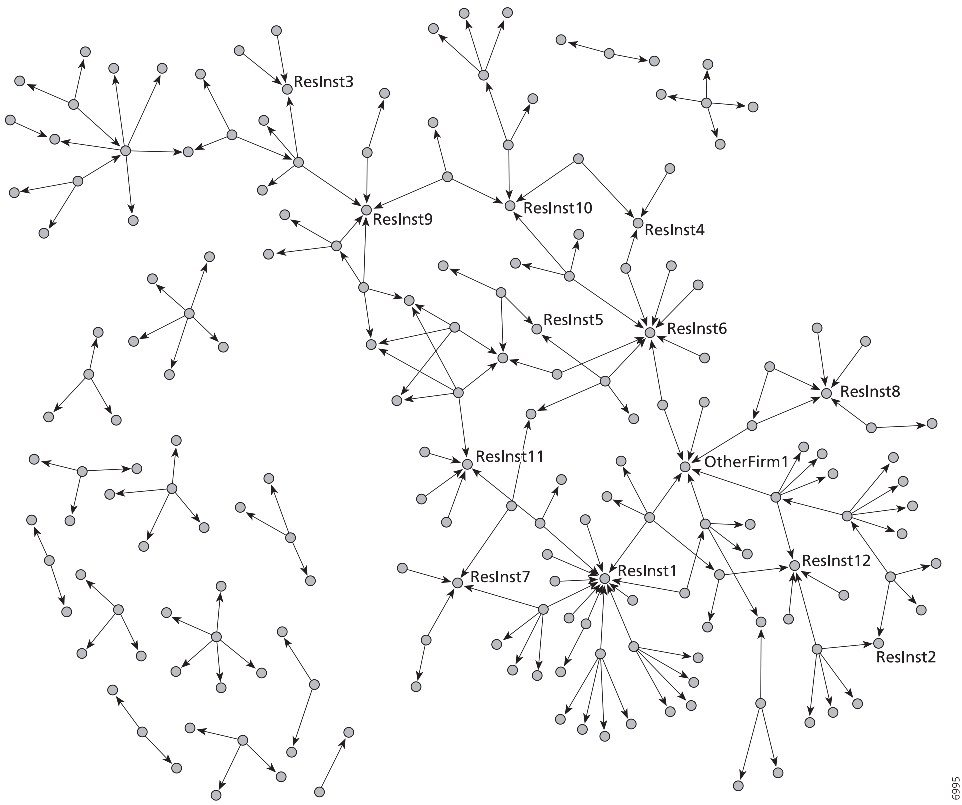

Figure 3.2 Network of collaboration of DDLSFs in 2004; The hubs in the network are labelled: ResInst = research institute; other firm = non-DDLSF firm

The networks of collaboration compiled by interorganisational relations of DDLSFs can be seen in Figures 3.1 and 3.2, in which an arrow pointing at a node represents a partner organisation mentioned by a DDLSF; an arrow can only point to a DDLSF if it was mentioned as an important partner by another DDLSF. The data on collaborative relations of DDLSFs depicted in Figures 3.1 and 3.2 are the sample data to be analysed.

3.3.2 Network analysis methods

As already noted by Powell et al. (2005), textbooks on network analysis methods like Wasserman and Faust (1994) do not treat methods to analyse the dynamics of networks over time. This implies that such dynamics can only be analysed by comparing network analysis measures over time. Changes in the network analysis measures used should reflect the changes to be observed in the sample network data displayed in Figures 3.1 and 3.2. These changes are 1) the integration of two main components into one larger main component without a large increase in the number of linkages between the nodes, and 2) the development of some more pronounced hubs.

The measures used to represent these two tendencies are the power degree of the frequency distribution of the number of linkages per node (Barabási and Albert, 1999), the maximum geodesic distance or diameter of the network and the average closeness index for centrality in the network (Wasserman and Faust, 1994).

A decreasing negative power degree over time reflects the development of structure in the network due to an increase in the number of linkages, especially between more connected nodes or hubs and less connected or remote nodes. A more or less developed hierarchical structure in which the average geodesic distance has declined then comes into existence (Barabási and Albert, 1999). A declining average geodesic distance reflects the small world character of the network (Watts and Strogatz, 1998). However, if the network becomes more structured and grows just slightly over time, then a change in average geodesic distance may be absent because both changes in the network have opposite effects on the change in average geodesic distance.[7] In order to check for this possible development of the power degree measure two additional measures have been used. The stretching out of the network, while the total number of linkages and nodes hardly grows, is better reflected by the increase in the maximum geodesic distance or diameter of the network (Wasserman and Faust, 1994: p. 111). In order to check for the development of structure in this network the change in the average closeness index for centrality in the network will be used (Wasserman and Faust, 1994: p. 201).

3.3.3 Results

Figure 3.1 reveals two main components of 45 and 100 nodes connected by 44 and 110 collaborative relations, respectively. Figure 3.2 shows one main component of 137 nodes connected by 150 collaborative relations. Apparently, the 2002 network of collaborative relations of DDLSFs achieved a higher level of integration in 2004 thereby indicating the development of one network from a fragmented network with isolated components or sub-networks. Furthermore, hubs of collaboration can be more clearly discerned in 2004 than in 2002. And the most important hubs in 2002 (ResInst 9 and 3) are not the same as those in 2004 (ResInst 1 and 6 and Otherfirm 1; see Table 3.1). This change in hubs indicates that the distribution of fitness for collaboration among partner organisations had not yet settled. Both changes in the network of collaborative relations of DDLSFs, together with the already reported low pace of growth of the network (1.3% per year), may be regarded as indicative of the early phase of development of the network.

Based on Figures 3.1 and 3.2, Table 3.1 presents the partner organisations with an indegree of two or more in both 2002 and 2004. Durable collaboration between a partner organisation and one or more DDLSFs is indicated by stable/repeated ties in 2004. Additionally, it should be mentioned that there were 11 partner organisations with only one repeated collaborative relation with a DDLSF in 2004. As already reported, at least 35 collaborative relations of the 187 mentioned in 2002 still exist in 2004, that is 29.2% after correction for non-response in 2004. This implies that the remaining 70.8% of the collaborative relations of DDLSFs in 2002 was not recorded in 2004. Of the 192 collaborative relations of DDLSFs in 2004 81.8% were new. Thus the network of collaborative relations of DDLSFs is highly volatile and this coincides with changes of partner organisations acting as hubs in the network. The hubs in 2004 are more pronounced than they were in 2002. This is reflected by their indegrees in Table 3.1 and consist in 2004 not only of research institutes, as was the case in 2002, but also of an established firm. It should also be noticed that all of the partner organisations reported in Table 3.1 are Dutch. Highly connected Dutch research institutes are mainly universities with a medical faculty. Technical universities are less connected.

Table 3.1 Partner organisations acting as hubs in the collaboration network of DDLSFs; (d) = Dutch. The organisations are numbered and shown in Figures 3.1 and 3.2.

Partner Organisation	Indegree 2002	Indegree 2004	No. of stable/repeated ties 2002-2004
OtherFirm 1 (d)	3	6	2
ResInst 1 (d)	4	12	2
ResInst 2 (d)	5	2	1
ResInst 3 (d)	6	3	0
ResInst 4 (d)	2	3	0
ResInst 5 (d)	3	2	1
ResInst 6 (d)	4	8	1
ResInst 7 (d)	2	4	1
ResInst 8 (d)	5	5	1
ResInst 9 (d)	6	5	2
RestInst 10 (d)	5	4	2
ResInst 11 (d)	4	5	2
ResInst 12 (d)	5	5	2

It now becomes interesting to see whether the developments in the network of collaborative relations of DDLSFs described above can also be derived from changes in the network analysis measures presented in the previous section. These measures are estimated and calculated for the whole network in 2002 and 2004 (see Table 3.2). To obtain these measures, collaborative relations of DDLSFs with partner organisations have been conceived as non-directional linkages.

The negative power degree increases by 45% between 2002 and 2004. Its value for 2004 coincides with the estimations of Gay and Dousset (2005) and Powell et al. (2005). During the period 2002-2004, the diameter of the largest component of the network increased by 33% while the average closeness index for centrality in the whole network increased by 20%. These changes in network analysis measures reflect the integration and stretching out of the network in which the reachability of nodes improved together with an increased markedness of hubs. Nevertheless, given that the number of linkages and nodes hardly grew between 2002 and 2004, the density of the network remained more or less the same thereby giving the network a large world character rather than a small world character.

Table 3.2 Network analysis measures for the network of collaborative relations of DDLSFs in 2002 and 2004

Networks	2002	2004
No. of nodes	197	205
No. of relationships	187	192
Power degree	-1.170	-1.695
Diameter*	12	16
Average closeness index for centrality	0.064	0.077

* As the geodesic distance between two isolated components of a network goes to infinity, the diameter of the network is by definition infinite. Therefore, the diameter of the largest component of the network in 2002 and 2004 is presented in Table 3.2

Table 3.3 Moments and power degree of the distribution of degrees of all responding DDLSFs and their named partner organisations

	2002	2004
Mean	1.89	1.87
Variance	2.30	2.78
Skewness	1.35	2.17
Kurtosis	0.71	6.98
Power degree	-1.170	-1.695
N	197	205

As the estimated value of the power degree in 2002 is slightly below -1.0, which is representative of a normally distributed random variable, the four moments (mean, variance, skewness and kurtosis) of the distribution of degrees of all DDLSFs responding to the name generation question in the 2002 and 2004 surveys (including the non-collaborating DDLSFs) (63+7=70 in 2002; 74+12=86 in 2004) and the partner organisations they mentioned (127 in 2002; 119 in 2004) have been estimated and presented in Table 3.3.

A skewness of 1.35 and a kurtosis of 0.71 are nearly admissible deviations from their theoretical values of zero for assuming a normal distribution of the indegrees of nodes in 2002 (Boomsma, 1983; Faber, 1988). However, the values of skewness and kurtosis estimated for the distribution of the degrees of nodes in 2004 indicate a significant deviation from normality. The reason for this change is the clearer markedness of hubs in the 2004 network of collaborative relations of DDLSFs giving the distribution of the degrees of nodes a 'fatter right tail' in 2004 than in 2002. This development is also reflected by the increase of the estimated negative power degree over time. Hence collaborative relations of DDLSFs in 2002 may be better characterised as a normally distributed random phenomenon, while the results obtained in 2004 could be indicative of a shift towards a power distribution.

The nature of these relations, and the changes therein, will be examined in order to search for more details of the collaborative relations of DDLSFs. To that end, the relative frequency distributions of these relations over some distinguished types of partner organisations and activity classes of collaboration in 2002 and 2004 are presented in Table 3.4. Of significance here is that R&D collaboration of all relations of DDLSFs grew from 70.5% to 80.5% in 2002 and 2004; i.e. a growth of 14%. Furthermore, organising market outlets (marketing/sales/distribution) grew from 7.5% in 2002 to 9.8% in 2004; i.e. a growth of 30%. All other specified activity classes of collaboration experienced a relative decline during the period 2002-2004 (as can be seen in the row providing information on the whole sample of partnerships).

From Table 3.4 it can be derived that R&D collaboration of DDLSFs with other DDLSFs and foreign established firms increases more than with Dutch and foreign research institutes and Dutch established firms. With respect to organising market outlets, the reported growth of collaborative relations of DDLSFs mostly concerned relationships with foreign firms. Apparently, DDLSFs became better acquainted with other DDLSFs and foreign firms over time.

How the collaboration of a DDLSF with a partner organisation is organised has only been looked into since 2004. The relative frequency distribution of collaborations of DDLSFs across specific forms of contractual arrangements and activity classes of relations derived from the survey data is presented in Table 3.5.

Table 3.4 Relative frequency distributions of collaborative relations of DDLSFs over types of partner organisation and activity classes

2002/2004	R&D	Marketing/ sales/ distribution	Production	R&D/ Production	Other	Total
Dutch DDLSF	5.8/9.2	0.6/0.6	1.2/0.0	0.6/0.0	0.0/0.0	8.1/9.8
Dutch other firm	11.6/12.6	1.7/0.6	1.7/2.3	0.6/0.0	2.3/0.6	17.9/16.1
Foreign firm	11.0/14.4	5.2/7.5	4.0/3.4	3.5/0.6	5.2/2.3	28.9/28.2
Dutch research institute	35.3/36.2	0.0/0.6	0.0/0.0	1.2/0.6	1.2/0.0	37.6/37.4
Foreign research institute	6.9/8.0	0.0/0.6	0.0/0.0	0.6/0.6	0.0/0.0	7.5/8.6
Total	70.5/80.5	7.5/9.8	6.9/5.7	6.4/1.1	8.7/2.9	100 %

2002: N = 173 (14 missing values)
2004: N = 174 (18 missing values)

With regard to R&D collaboration, the most important arrangements were joint R&D and R&D outsourcing. Typically, there were very few direct investments in R&D activities of DDLSFs by partner organisations. Furthermore, joint ventures are virtually absent here. With respect to organising market outlets, the dominant arrangement was licensing.

In summary, the network of collaborative relations of DDLSFs expanded between 2002 and 2004 in the total number of DDLSFs involved (17.5%) but much less in the total number of linkages (2.5%). The relative number of non-collaborating DDLSFs grew from 6% in 2002 to 11% in 2004. The network stretched out and became more integrated but did not become more densely connected. Hubs in the network became better discernable but were not stable over time. This volatility was generally present; only 29.2% of the relationships were stable. These developments are reflected by changes in the estimated power degree measure as well as changes in the diameter of the largest component of the network and the average closeness index for centrality of the whole network. More than 70% of the collaborative relations of DDLSFs were aimed at R&D collaboration, especially in the form of joint R&D and R&D outsourcing, and almost 10% of the relations were aimed at organising market outlets. These findings illustrate the

Table 3.5 Relative frequency distribution of collaborative relations of DDLSFs across forms of contractual arrangement and activity classes

2004	R&D	Marketing/ sales/ distribution	Production	R&D/ Production	Other	Total
Joint Venture	1.8	0.6	1.2	0.0	0.0	3.6
Licensing	6.6	4.8	3.0	0.0	0.0	14.4
Joint R&D	50.6	0.6	0.0	0.0	0.6	51.8
R&D Outsourcing	12.0	0.0	0.0	0.6	0.0	12.7
Direct Investment	3.0	0.0	0.0	0.0	0.0	3.0
Other	5.4	4.2	1.8	0.6	2.4	14.4
Total	79.5	10.2	6.0	1.2	3.0	100%

N = 166 (26 missing values)

early stage of development of the DDLSFs that are more concentrated on conducting R&D than on commercialisation. Additionally, these relations also became more organisationally and geographically differentiated as more other firms and foreign established firms became involved.

From these summarised results it can be derived whether or not the conjectures formulated in Section 3.2 are confirmed by our findings. Conjecture 1, stating that the initial network is relatively fragmented, is confirmed. Conjecture 2, stating an increase in the number of nodes and linkages connecting them over time, is partially confirmed and rejected. The expected increase in nodes is confirmed, but the expected increase in linkages is rejected. Conjecture 3, stating research institutes to be the dominant hubs in early network development, is confirmed. Conjecture 4, stating that established firms become more important in network relations over time, is confirmed. Conjecture 5, stating that the number of non-collaborating DDLSFs will be small and diminish over time, is only partly confirmed. While the number of non-collaborating DDLSFs is relatively small, their number is increasing rather than diminishing. The finding that the network became more structured over time provides partial confirmation for Conjecture 6. Insights into the importance of endogenous network effects will be given in the next section, enabling us to address the second part of this final conjecture.

3.3.4 Further analysis

As stated earlier, the collaboration network of DDLSFs was highly volatile between 2002 and 2004. While R&D collaboration was the main focus of DDLSFs, collaboration on commercialisation is growing. This differentiation in types of partnerships was accompanied by organisational differentiation. This means that collaboration on R&D and commercialisation were not concentrated on the same partner organisations acting as hubs in the network but are differentiated between distinct types of organisations. Some of the most important partner organisations acting as hubs in the 2002 network were replaced by others in 2004.

An argument presented by Gay and Dousset (2005) for these developments is the pace of succession and differentiation of technologies in the field of life sciences. This implies that organisations active within such a field are constantly searching for the most promising and newest complementary technologies and therefore often switch between partner organisations. Gulati and Gargiulo (1999) show that as structure develops within a network, reputation-related effects start to exert an influence on the subsequent formation of new relations. However, if the complementary competences required by DDLSFs are found outside the network, new partner organisations are added.

In order to examine the extent to which new organisations are added to the network by partnering with a DDLSF, the sample of collaborative relationships of these firms in 2004 has been broken down in Table 3.6. In Table 3.6 the collaborative relationships of DDLSFs already established in 2002 but non-responsive to the 2002 survey are presented as a special category; i.e. 16 DDLSFs with 46 collaborative relationships in 2004. These are not analysed in greater detail because it is unknown whether these 18 relations in 2004 (39%) were continued or new relations were formed with partner organisations that were already members of the network in 2002.

From Table 3.6 it can be derived that 1) 24% (35) of all collaborative relations of DDLSFs were continued, 2) 34% (50) of the new relations in 2004 were with partners already active in the network in 2002, possibly indicating the effects of information/knowledge dissemination; and 3) 42% (61) of the relations were formed with organisations not yet part of the network in 2004. These findings show that the majority of newly established relationships in 2004 compared to

Table 3.6 Number of DDLSFs and their collaborative relations in 2004 with partner organisations already existing in 2002 and new in 2004

		Relations with			
		existing partner organisations in 2002		new partner organisations in 2004	total
DDLSFs in 2004		**stable relations**	**new relations**	**new relations**	**all**
collaborating in 2002	26	35	9	33	77
non-collaborating in 2002	3	0	4	3	7
new in 2003-2004	29	0	37	25	62
subtotal	58	35	50	61	146
non-responding in 2002	16	18		28	46
total	74	103		89	192

2002 are relationships with organisations that were not part of the network in 2002, indicating a search for novelty outside the network (Powell et al., 2005). Of the remaining 24% of the relations that were part of the network in 2002 and 2004, we have not been able to determine whether they are actually continued or renewed. These findings do not provide confirmation for the second part of Conjecture 6, in which the importance of endogenous network effects on the formation of new partnerships was proposed. Of the relations of collaborating DDLSFs already established in 2002 (77) 45% were stable, 12% were new relations with organisations already active in the network in 2002 and 43% were new with organisations previously not part of the network. New and in 2002 non-collaborating DDLSFs mostly engaged in partnerships with organisations that were already part of the network. Overall, 76% (50+61=111/146) of the collaboration network of DDLSFs is volatile.

3.4 Discussion

In this study we used an indicator for interorganisational collaboration that differs from that used in most other studies on the subject of collaboration networks in the life sciences and biotechnology. We measured the actual involvement in collaboration in a multi-wave survey, which enabled us to show the dynamics of the network of collaboration compiled by DDLSFs. Even though we used this different approach our results are for the most part in accordance with those obtained in other studies on networks in the life sciences and biotechnology. Within the emerging network, R&D collaborations with research institutes are dominant, as was the case in the study conducted by Owen-Smith and Powell (2004). While R&D remains by far the most important interorganisational activity, the importance of marketing and sales collaborations increases over time, indicating an increasing significance of the commercialisation of technology. This is in accordance with studies conducted by Powell et al. (2005) and Owen-Smith and Powell (2003), as also is the increasing importance of R&D agreements between DDLSFs. However, relationships based solely on financing are not of importance in the network of DDLSFs. Additionally, it was shown that the extent to which relationships were continued or renewed was rather low given that only 29.2% of the relations present in 2002 were also present in 2004. This indicates that the network was highly volatile. Our results regarding the power degree of the network are ultimately similar to those of Gay and Dousset (2005) and Powell et al. (2005). However, the change in estimated power degree between 2002 and 2004 could be indicative of a transition of the collaborative network studied here.

As the negative power degree values estimated for the DDLSFs network grow to roughly the same values estimated by Gay and Dousset (2005) and Powell et al. (2005) for much longer lasting networks of life sciences firms, it seems that the developments in collaborative networks of life sciences firms are typical for the industry. One reason, as suggested by Gay and Dousset (2005), could be the pace of succession and differentiation of life sciences technologies and the related influx of new DDLSFs into the network (25% in 2004). A related reason could be the increasing amount of knowledge of and information about the organisations in the network due to the existence of the network, thereby offering new opportunities for collaboration over time (Gulati and Gargiulo, 1999). Another reason may be a combination of both reasons. Organisations possessing better and/or more specialised technologies become more well-known to others thanks to their continued membership of the network. All these reasons result in a high degree of volatility of the collaborative network of DDLSFs and, consequently, in a rather large decay of collaborative relations. Such volatility and decay are also found in networks of interpersonal collaborative relations among professionals in financial organisations (Burt, 2000).

One reason for the high volatility and modest structuring of the collaboration networks of Dutch dedicated life sciences firms could be that it is an inherent characteristic of the technological field. If, as Gay and Dousset (2005) suggest, these characteristics of network development are due to the technological diversity of the field of life sciences and the pace of diversification and succession of the technologies developed in this field, then from an organisational perspective the implication of this suggestion may be that biotech firms can only develop viable product portfolios through network collaboration. Consequently, the life sciences industry becomes a true network industry in contrast to supply-chain industries such as the manufacturing and services sectors. The nature of a network industry then promotes integration of the collaborative network and growth of its membership but with less hierarchical structuring than found in other business networks.

3.5 Conclusion

The central research question of this chapter was: "*To what extent and in what way did the network of interorganisational collaborations of Dutch dedicated life sciences firms emerge and develop from 2002 to 2004?*" As the population of DDLSFs is known for both years of observation, the formation, continuation and discontinuation of their collaborative relations together with their non-collaboration can be assessed by using surveys. Consequently, the volatility of the network can be addressed. Most studies have not been able to do this as the most frequently used indicator was the formation of collaborative relations and not the involvement in collaboration at successive moments in time (see for instance Gay and Dousset (2005) and Roijakkers and Hagedoorn (2006)).

Taking into account the measures of network development that have been used in this chapter, it can be concluded that from 2002 to 2004 there has been increasing integration and structuring of the network of collaborations, while the overall growth of the network in terms of an increasing number of linkages, was rather low i.e. 1.3 % per year on average. There is an increased markedness of major hubs, as well as an increased reachability of the actors in the network. Overall, only 29.2% of the relationships in the 2002 network still existed in 2004. Over time, there is an increasing focus on R&D relationships as well as on organising market outlets. R&D relationships with other DDLSFs and foreign established firms gain importance. These outcomes are in line with the results of other studies on networks in biotechnology and the life sciences discussed earlier.

A theoretical argument for the development of the network studied can be related to the newness of successive technologies possessed by new entrants or organisations which, although they were already in the network, had gone unnoticed by other organisations. This results in a high level of 'switching' collaborative relations by DDLSFs over time and thus in a highly volatile network. Nevertheless, whether or not this is the theoretical argument for the observed network dynamics cannot be determined.

The estimated low values of the negative power degree for the whole network together with the volatility of hubs over time, i.e. the absence of preferential attachment, raises the question whether collaboration by DDLSFs is a normally distributed random phenomenon and not a scale-free phenomenon with a power distribution of degrees of nodes caused by preferential attachment. To answer this question the four moments of the degree distribution and its power degree for the whole network in 2002 and 2004 have been estimated. These estimated moments and power degrees show that collaboration by DDLSFs is developing from almost a random phenomenon in 2002 into a more structured network in 2004. Future research into additional waves of data on partners of DDLSFs for 2005 and subsequent years will be necessary to validate this derived tendency of structural change.

4 Effects of patent and venture capital acquisition on partnering by young Dutch dedicated life sciences firms in 2002

4.1 Introduction

Over the past few decades the number of interorganisational collaborations has increased substantially, especially where R&D collaborations are concerned (Hagedoorn, 2002). For new technology-based industries such as the life sciences industry, such collaborations are regarded as going hand in hand with viable business development (Powell et al., 1996; Niosi, 2003).

In many West European countries, further development of the life sciences industry is supported by governmental programmes. Development of such a high technology, science-based industry is considered important in these countries for the industry's contribution to achieving a knowledge-based economy which is capable of sustaining future economic growth. For that reason, the Dutch Ministry of Economic Affairs started the BioPartner Network programme in 2000 (Ministry of Economic Affairs, 1999). In order to monitor the success of this programme, a register was set up of all Dutch dedicated life sciences firms (DDLSFs) based on the records of the Dutch Chamber of Commerce. This register is updated annually. Since 2002 a survey has been sent to the CEOs of the DDLSFs on an annual basis for the purpose of monitoring the development of the Dutch life sciences industry. This annual survey produces unique data on the population of DDLSFs, i.e. their collaborative relations with one another, and also with established diversified firms and research institutes and various firm-related characteristics.

Analysis of the collaboration network of DDLSFs in 2002 revealed an almost random distribution of collaborative relations indicative of a life sciences industry in its very early stage of development[8] (Chapter 3 of this thesis). Such an almost random distribution of partnering by DDLSFs is representative of an unstructured collaboration network in which there are virtually no endogenous network effects on that partnering. This implies that an explanation based on such endogenous effects is not obvious (Gulati and Gargiulo, 1999) and that an alternative explanation for partnering by DDLSFs in 2002 should be developed. In this chapter we develop a resource-based explanation, as is advocated by the resource-based and resource dependence views of the firm (Penrose, 1959; Pfeffer and Salancik, 1978; Wernerfelt, 1984). Consequently, the research question to be examined is formulated as:

What resource stocks affect interorganisational partnering by young Dutch dedicated life sciences firms?

In order to provide an answer to this research question a theoretical framework will be developed in the following section. Subsequently, a description will be given of the data collection method that was used and the measurement of the concepts discerned. Next, the statistical methods used for testing the hypotheses will also be discussed. After that, the results obtained will be presented and interpreted. Subsequently, the management and policy implications of the results for life sciences start-ups will be addressed. A discussion of the research carried out and the conclusions to be drawn from the results conclude this chapter.

4.2 Theoretical framework

In the Resource-Based View of the firm (RBV), a firm's resource portfolio is pivotal in explaining strategic firm behaviour. In this respect resources are defined as "those (tangible and intangible) assets which are tied semipermanently to the firm" (Wernerfelt, 1984: p. 172). This RBV provides a somewhat internally oriented view on firm behaviour as it is mainly focused on the development of distinctive resources within individual firms. It should therefore at least be complemented with the Resource Dependence perspective, in which explicit attention is given to obtaining access to complementary resources of other organisations within the environment of the focal firm (Pfeffer and Salancik, 1978). This notion of complementarities of resources of organisations is especially relevant in the study of organisational behaviour in high technology, science-based industries. One of the implications of operating in a high technology industry is that firms have to cope with rapid technological change, making it difficult for them to determine what technological fields to focus on. Also, the pace of technological change and the increasing complexity of successive technologies make it impossible for an individual firm to possess all the resources required to conduct R&D in-house. This results in a distribution of resources and capabilities across organisations within an industry. Access to complementary knowledge and resources then becomes pivotal rather than actual acquisition of knowledge and resources (Grant and Baden-Fuller, 2004). This distribution of resources drives the emergence of networks of collaboration among high technology organisations with many lateral relations. Firms operating in emerging high technology industries use networks of interorganisational collaboration to gain access to complementary resources and competences required for engaging in R&D. Consequently, the specific resources of individual organisations constitute a pivotal criterion in partner selection (Hitt et al., 2000).

When explaining the collaborative behaviour of starting organisations, aspects related to the liability of newness need to be addressed explicitly (Stinchcombe, 1965). Compared with established organisations, start-ups have to overcome several additional hurdles in order to become and remain successful. Among these hurdles are the lack of reputation and lack of visibility within a specific industry or sector. In sectors in which resources are heavily dispersed among actors, this liability of newness results in a liability of unconnectedness (Powell et al., 1996). Improving the reputation and visibility is therefore of critical importance to start-ups active in a high technology sector.

In the case of a new technology-based firm, the extent to which its technology is well known and regarded as being promising provides one mechanism by which the firm can gain visibility and establish a reputation for it to be considered as a potential partner by other organisations (Ahuja, 2000). In this respect, acquiring a patent is considered to be a prerequisite as this is an indicator of the quality of the underlying technological knowledge (Stuart et al., 1999; Niosi, 2003). The acquisition of a patent by a start-up therefore positively contributes to its reputation and visibility within a technology-based business field and thereby enables firms to partner (Mazzoleni and Nelson, 1998; Sakakibara, 2002; Baum and Silverman, 2004; Thumm, 2004).

To further improve its reputation, it is also important that the strategic choices made concerning the exploitation of a patent are considered to be both adequate and promising. The acquisition of venture capital may be conceived as a relevant indicator of the extent to which the proposals for exploitation of the firm's patent have obtained external approval and are considered promising[9] (Baum and Silverman, 2004). It needs to be noted, however, that in the process of due diligence of a venture capitalist, the question whether or not a firm has already obtained a patent is important as a venture capitalist has limited competences to evaluate the actual quality of a firm's technology portfolio. In this respect, patent acquisition represents a useful proxy for the evaluation of this quality by venture capitalists (Niosi, 2003; Baum and Silverman, 2004). Furthermore, the initial exploitation of the patent should be successful in terms of generating revenues. Both patent acquisition and successful initial patent exploitation demonstrate the viability of the start-up, which is crucial for further business development to be financed with venture capital (Tidd et al., 2001; Christensen and Raynor, 2003). Overall, it may be derived that the acquisition of a patent and venture capital both contribute to the reputation and visibility of a high technology start-up and therefore to partnering. In turn, venture capital acquisition is influenced by patent acquisition and exploitation.

Apart from the reputation and visibility enhancing effects ascribed to patent and venture capital acquisition, the partnering rate of start-ups will also depend on how much information they possess about their own and complementary fields of knowledge and about the organisations active in these fields that might be considered as potential partners. The amount and usage of this information will vary with the size of the management team of the start-up (Eisenhardt and Bird Schoonhoven, 1996) as the management team may be expected to be a firm's primary link with its environment. The ability of a start-up's management team to mobilise this source of information for deliberated selection of suitable partner organisations may be conceived as its social capital. This social capital acts as a directional profiler of the reputation-related effects of patent and venture capital acquisition towards other organisations, thereby stimulating partnering by a start-up. This is related to the idea that partner selection based on resource portfolios is conducted within the boundaries of the opportunity set of the firm (Seabright et al., 1992).

Further business development in the early development stage of a start-up primarily concerns improving the quality and strategic positioning of its product portfolio in order to expand the exploitation of its patent(s) and diversifying its markets (Christensen and Raynor, 2003). For improving its product portfolio, complementary knowledge and technologies that are not possessed by the start-up are necessary. As discussed before, partnering with other organisations can be used to fulfil this need for complementary resources. Consequently, the partnering rate of start-ups in high technology, science-based industries such as the life sciences indicates their involvement in further business development to strengthen their viability in the future. Establishing partnerships, however, requires visibility of a start-up as an interesting partner for other organisations in its environment. This visibility will be positively affected by their acquisition of patents and venture capital and the propagation thereof by the management team.

In the previous paragraphs four concepts were introduced that are regarded as playing an important role in the partnering by start-ups in high technology, science-based sectors such as the life sciences industry, namely patent acquisition, successful initial business development based on initial patent exploitation, venture capital acquisition and the management team. But how these concepts affect partnering and each other has only been partly addressed and will be further elaborated on below. In substantiating the explanations of these effects, we have mostly concentrated on referring to papers on high technology sectors as these may be considered to be the most relevant.

The effect of patent acquisition on partnering can be exerted through two different mechanisms. If patent acquisition exerts an opportunity-based reputation-related effect, as already explained above, then this effect will be positive (Ahuja, 2000; Baum et al., 2000). However, patent acquisition can also negatively influence partnering, namely if an increasing number of patents acquired decreases the need for obtaining external access to complementary knowledge and competences. In other words, a start-up that has one or a few patents may experience an inducement to partner in order to obtain access to complementary competences necessary for subsequent development and commercialisation of the patented technology (Mazzoleni and Nelson, 1998). This would imply that an inducement-related effect is dominant (Ahuja, 2000). Hence, the following opposite hypotheses are formulated.

H1a: *A larger number of patents stimulates the partnering rate.*
H1b: *A smaller number of patents stimulates the partnering rate.*

A unique technological basis reflected in patent acquisition is considered a prerequisite for a start-up to initiate a business in the life sciences industry. On the one hand, the size of this technological basis, reflected in the number of patents, can positively affect the scale of initial business operations as it increases the number of technological options that can be commercialised. On the other hand, an extensive technological basis also increases the technological complexity to be dealt with by a start-up, which may limit the scale of initial business operations deployed. Since, due to lack of empirical evidence it cannot be decided beforehand which of these two effects is dominant, two opposite hypotheses are formulated.

H2a: *A larger number of patents stimulates the scale of initial business development.*
H2b: *A larger number of patents limits the scale of initial business development.*

Patent acquisition and successful initial business development have been argued before to stimulate venture capital acquisition. In turn, venture capital acquisition is likely to have a positive effect on the partnering rate of a start-up. Hence, three hypotheses can be formulated.

H3: *A larger number of patents stimulates venture capital acquisition.*
H4: *More successful initial business development stimulates venture capital acquisition.*
H5: *More venture capital acquisition stimulates the partnering rate.*

The effect described in Hypothesis 3 already has empirical support (Baum and Silverman, 2004). With respect to the fifth hypothesis it should be noted that the expected positive effect of venture capital acquisition on the partnering rate represents an inducement as well as an opportunity for partnering. The inducement consists of the obligation to successfully expand the business operations of the start-up after venture capital acquisition by engaging in partnerships.

The opportunity consists of the increased attractiveness of the start-up as a partner of other organisations after venture capital acquisition by that start-up.

It is argued that the degree to which a start-up has information about its business environment and interesting partner organisations therein varies with the size of the start-up's management team (Eisenhardt and Bird Schoonhoven, 1996). Having access to such information is believed to have a positive effect on partnering by the start-up because it helps to find and contact potentially interesting partner organisations and increases a start-up's chances of being found by these potential partners (Eisenhardt and Bird Schoonhoven, 1996). Hence, the following hypothesis can be formulated:

H6: *A larger management team stimulates the partnering rate.*

Subsequently, the question arises what factors determine the size of a start-up's management team. The size of the management team is likely to grow along with a growth of the scale of business activities employed by a firm. In this respect, two factors have already been mentioned: the scale of initial business development and the complexity of the technological basis of the start-up reflected in its number of patents. As the degree of complexity of the technological basis of a start-up in the life sciences industry is assumed to vary positively with the size of this technological basis (i.e. the number of patents), a direct positive effect of its number of patents on the size of its management team may be expected. The scale of initial business development may be expected to have a similar, positive influence on the size of the management team. Therefore, two hypotheses can be formulated.

H7: *More successful initial business development stimulates the size of the management team.*
H8: *A larger number of patents stimulates the size of the management team.*

Combining the eight hypotheses about the causal effects among the five concepts mentioned therein gives the conceptual model of partnering behaviour by start-ups in the life sciences industry depicted below in Figure 4.1. In the following section, the empirical data used to test the hypothesised relations in this model will be discussed.

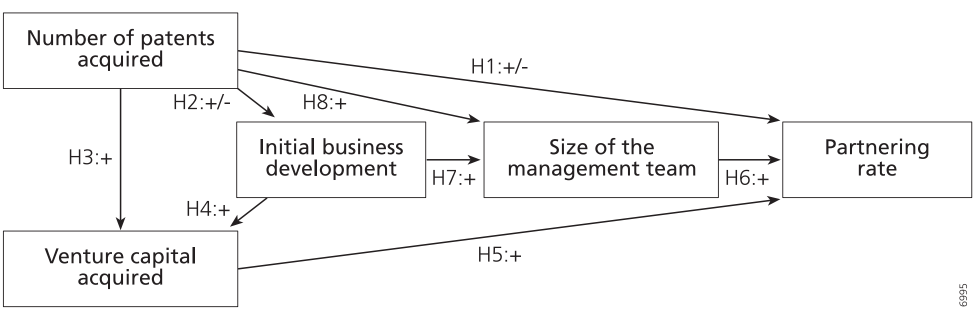

Figure 4.1 Conceptual model of the partnering rate of start-ups in the life sciences industry

4.3 Research methods

The data used to test the conceptual model are obtained from the survey distributed among the known population of DDLSFs in 2002. The questionnaire was sent to 126 DDLSFs and contained questions on possible indicators of the concepts in Figure 4.1, such as the number of collaborative relations a respondent is engaged in, the amount of venture capital acquired, the number of patents acquired, the number of managers, the change in turnover since 2001, as well as data on the total number of employees, the change in number of employees since 2001, and the year of founding. However, the data on the amount of acquired venture capital and the number of acquired patents represent accumulations over time as many DDLSFs were established before 2002. In order to check for contamination of test results due to differences in firm and business development over time, control variables are added to the conceptual model, namely 'firm age' and 'firm size in 2001'. The control variable 'firm size in 2001' is a proxy of business development before 2002 as it merely represents its condensate reflecting previously built up financial, human and technological capabilities. By regressing the concepts in Figure 4.1 on both control variables the effects of accumulation over time due to earlier firm establishment and business development before 2002 can be separated from the effects contained in H1-H8. Furthermore, only DDLSFs not older than five years are selected from the set of DDLSFs giving the intended sample of young DDLSFs or start-ups.

The 2002 BioPartner Network questionnaire sent to 126 registered DDLSFs was (partly) completed and returned by 110 DDLSFs. Imposing the five years restriction reduced the set of respondents to 81 DDLSFs. Sorting out respondents that failed to answer one of the questions on the indicators mentioned above using listwise deletion resulted in a reduced set of 39 DDLSFs; that is a response rate of (39/81)*(110/126)*100% = 42%. The distribution of the 39 selected young DDLSFs over the no/yes categories of patent and venture capital acquisition is shown in Table 4.1 below.

This distribution is not random as its Chi-square value is 7.122 with 1 degree of freedom is larger than the critical Chi-square of 6.635 for a 99% confidence interval around zero (Wonnacott and Wonnacott, 1990).[10] This test shows that both patent and venture capital acquisition were desired by young DDLSFs. This already reflects the expected reputation-related effects of the acquisition of at least one patent and venture capital as prerequisites for survival of a start-up in the life sciences.

The concepts in Figure 4.1 and the control variables mentioned before are operationalised for all the selected young DDLSF as follows:

- 'number of patents' is measured as the number of patents acquired on December 31, 2002,
- 'venture capital' is measured as the amount of venture capital acquired on December 31, 2002 in ten thousands of euros,

Table 4.1 The distribution of 39 young DDLSFs with and/or without patents and venture capital in 2002

		venture capital	
		no	**yes**
patents	**no**	8	4
	yes	6	21

- 'current business development' is measured as the yearly change in turnover on December 31, 2002 in ten thousands of euros,
- 'size of the management team' is measured as the number of managers on December 31, 2002,
- 'partnering rate' is measured as the number of collaborative relations actively engaged in on December 31, 2002,
- 'firm age' is measured as the age in years, calculated as 2002 minus the year of establishment, and
- 'firm size in 2001' is measured as the number of employees on December 31, 2002 minus the yearly change in number of employees during 2002.

Additionally, the empirical variables acting as indicators of the concepts in Figure 4.1 are expected to vary positively with the previously defined indicators of the control variables 'firm age' and 'firm size in 2001'. These effects and those specified in H1-H8 will be tested using the data derived from the Dutch BioPartner Network survey 2002 discussed earlier.

4.4 Methods of analysis

In order to test the hypotheses H1-H8 and the effects of the control variables a linear model can be specified consisting of the equations given in Table 4.2.

This linear model is specified in the computer program LISREL® (Jöreskog and Sörbom, 1993) in order to obtain minimum variance unbiased estimates of the unknown constant parameters b_1-b_8, f_1-f_5 and a_1-a_5 by using the maximum likelihood (ML) method. Apart from these optimal estimates and the associated standard errors and t-values, LISREL also estimates the fit of the model to the input matrix S by means of a Chi-square (χ^2)-based goodness of fit measure and its associated number of degrees of freedom df and probability p. Additionally, LISREL produces modification indices for non-specified effects fixed at a value equal to zero. These modification indices are estimates of the decrease of the Chi-square value of goodness of fit for individual

Table 4.2 Parameters to be estimated (corresponding hypothesis with proposed effect is given between brackets)

Dependent variables	Firm size 2001	Firm age	Number of patents	Current business development	Venture capital	Size of the management team
Number of patents	f_1	a_1				
Current business development	f_2	a_2	b_1 (H2: +/-)			
Venture capital	f_3	a_3	b_2 (H3: +)	b_3 (H4: +)		
Size of the management team	f_4	a_4	b_4 (H8: +)	b_5 (H7: +)		
Partnering rate	f_5	a_5	b_6 (H1: +/-)		b_7 (H5: +)	b_8 (H6: +)

non-specified fixed parameters when they are also specified to be estimated. Modification indices are given by LISREL for improving the estimated model's specification on statistical grounds.

However, it can be argued that the measurement scales of the empirical variables are mostly different from the interval and ratio scales required for linear models and that the specification of H1-H8 and the effects of the control variables as linear relations is incorrect therefore. 'number of patents', 'size of the management team', 'partnering rate' and 'firm age' are typical discrete count variables with many replications of values in the data set. 'venture capital' and 'firm size in 2001' are censored variables with a lower threshold at zero. Only 'current business development' is measured on an interval scale. So, there are discrete, censored and continuous variables in the data set. Fortunately, LISREL's pre-processor PRELIS™ (Jöreskog and Sörbom, 1995) contains ML correlation estimation procedures for such variables based on the polychoric correlation for two discrete variables (Olsson, 1979), the polyserial correlation for discrete and continuous variables (Olsson et al., 1982), the Pearson correlation for two continuous variables (Wonnacott and Wonnacott, 1990) and combinations thereof for estimating the correlation between a discrete or continuous variable and a censored variable (Faber, 1991). These procedures calculate ML estimates of correlations based on the assumption of underlying normally distributed continuous variables. The resulting estimated correlations are shown to be superior to any other measure of association (Jöreskog and Sörbom, 1995: 8-18). The correlation matrix resulting from applying the procedures programmed in PRELIS can then be used as the input matrix S in LISREL for the ML estimation of the equations presented in Table 4.2.

4.5 Results

The ML estimation conducted produces the estimates of the unknown constant parameters b_1-b_8, f_1-f_5 and a_1-a_5 (with t-values) given in Table 4.3. With a correlation of 'firm size 2001' and 'firm age' of 0.15 (t-value: 0.93) and a Chi-square value of 4.79 (df=4) giving a probability of 0.31 for the goodness of fit. The critical absolute t-value for a one-tailed test with a 95% confidence interval of the estimated regression coefficients is $t_{0.05}$=1.69.

The results show that 'firm age' has a significant negative effect on the 'size of the management team' whereas a positive effect was expected. As 'firm age' is unrelated to all other variables in the model, no plausible argument can be given for this negative effect. Consequently, 'firm age' is removed from the model after which it is ML estimated again. After that, still two insignificant effects remain, namely the effect of 'firm size in 2001' on the 'size of the management team' and the effect of the 'size of the management team' on the 'partnering rate'. Again these insignificant effects are removed before the next ML estimation is carried out. Now, all remaining specified effects are significant. Furthermore, the modification index of the effect of the 'size of the management team' on 'venture capital' indicates a significant positive effect. This effect implies that the knowledge of and contacts with other organisations held by the management team is utilised to find venture capitalists providing additional financing, which in turn stimulates partnering. After specification of this effect in the model its final estimation produces the results depicted in Figure 4.2[11].

A Chi-square value of 1.02 (df =5) giving a probability of 0.96 makes the fit of the estimated model to the input matrix S excellent. Figure 4.2 shows that hypotheses H1b, H2b, H3, H4, H5, H7 and H8 are confirmed as well as the expected positive effects of the control variable 'firm

Table 4.3 Estimation of the parameters

Dependent variables	Firm size 2001	Firm age	Number of patents	Current business development	Venture capital	Size of the management team	R^2
Number of patents	0.71 (5.90)	-0.17 (-1.43)					0.49
Current business development	0.80 (4.35)	0.13 (0.98)	-0.49 (-2.71)				0.40
Venture capital	0.29 (1.70)	-0.14 (-1.40)	0.41 (2.74)	0.36 (2.89)			0.66
Size of the management team	0.10 (0.56)	-0.24 (-2.36)	0.22 (1.49)	0.73 (5.84)			0.66
Partnering rate	0.17 (0.94)	0.10 (0.98)	-0.42 (-2.83)		0.78 (4.81)	0.12 (0.96)	0.63

size in 2001' except for its effect on the 'size of the management team'. Apparently, the 'size of the management team' depends solely on 'current business development' and the size of the technological basis (i.e. 'number of patents acquired') of the start-up. Furthermore, the expected direct positive effect of the 'size of the management team' on the 'partnering rate' turns out to be insignificant thereby rejecting Hypothesis 6. This effect is indicated by LISREL to be exerted through the variable 'venture capital acquired'. In sum, the validation of all but one hypothesis specified in the conceptual model indicates that the conceptual model provides a substantial but not complete explanation for the partnering rate of young DDLSFs with other organisations (R^2=0.62). The dominant role of patent and venture capital acquisition in this partnering by

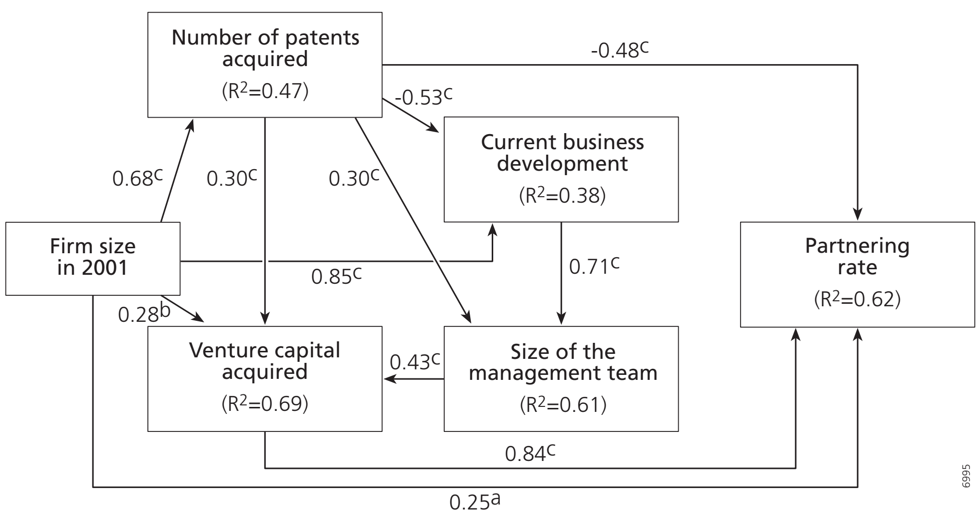

Figure 4.2 Estimated model of the partnering rate of Dutch dedicated life sciences firms in 2002 (N=39) (with [a]: p<0.10, [b]: p<0.05 and [c]: p<0.01)

young DDLSFs, which is undertaken for further business development, is now evident as is the minor role of prior business development.

Next to the estimated direct effects discussed above, it is also possible to estimate all indirect effects operating in Figure 4.2[12]. Variables initiating sequences of indirect effects might play a larger role in explaining partnering by DDLSFs than is apparent from just the direct effects given in Figure 4.2. The total effect of variables having both a direct and indirect effect on a specific dependent variable is given, which is calculated by adding the direct and indirect effects. The values of direct effects listed in Table 4.4 are equal to those in Figure 4.2.

Table 4.4 shows that the total inducement to partner generated by having only a few patents is weaker than its direct effect suggests. Furthermore, it can be derived that prior business development (Firm size 2001), current business development and the size of the management team make a significant indirect contribution to the partnering rate of young DDLSFs. Thus, business development and knowledge of the environment are more important for partnering by young DDLSFs than shown by the direct effects in Figure 4.2. The amount of venture capital acquired by a start-up largely depends on prior business development (Firm size 2001) as well as on the size of the management team. Moreover, the positive effect of current business development on venture capital acquisition is also substantial, whereas venture capital acquisition is least determined by patent acquisition. Hence, it seems that venture capital acquisition is more dependent on successful business development than on unique technological competences. Table 4.4 also shows that the size of the management team not only depends on current business development but also on prior business development (Firm size 2001) as may be expected, but indirectly. Furthermore, the direct effect of the number of patents acquired on the size of the management team is neutralised by the indirect effects through current business development. The total effect of prior business development (Firm size 2001) on current business development is also lower than suggested by the direct effect due to the negative direct effect of patent acquisition on current business development.

Table 4.4 Total effects of each explanatory variable on all dependent variables in the estimated model of the partnering rate of DDLSFs in 2002 (N=39)

Dependent Variables	**Explanatory variables**				
	Venture capital	**Size of the management team**	**Current business development**	**Number of patents**	**Firm size in 2001**
Partnering rate	0.84 (d)	0.36 (i)	0.25 (i)	-0.25	0.53
Venture capital		0.43 (d)	0.30 (i)	0.27	0.72
Size of the management team			0.71 (d)	-0.07 ^{ns}	0.55 (i)
Current business development				-0.53 (d)	0.48
Number of patents					0.68 (d)

(d) only direct effect; (i) only indirect effect; ^{ns} *p>0.10*.

4.6 Management and policy implications

The results presented in Figure 4.2 show two negative effects in the model of partnering by individual young DDLSFs, namely those of acquired patents on the number of collaborative relations and acquired patents on current business development. These effects put a maximum on the number of collaborative relations actively engaged in by young DDLSFs.

From the perspective of managing a young DDLSF this implies that focusing on expanding the technological basis of the firm in terms of more patents in order to acquire more venture capital for future business development through partnering inherently entails the risk of neglecting the urgency of current business development. Such a strategy can be pursued when founding the firm, but over the course of time this strategy should be changed into a strategy that aims at boosting sales and revenues in existing and new markets with services and products based on a medium-sized and not maximised technology portfolio. In other words, commercialisation is necessary for future viability. In biotechnology, this is reflected in the trend of increasing proliferation of hybrid business models that include services or out-licensing activities which are used to secure short term revenues (Ernst & Young, 2004; Willemstein et al., 2007)

From the perspective of venture capitalist policy, the negative effects mentioned imply that the financing proposals of young DDLSFs to further extend the technological basis by means of the acquisition of additional patents should be assessed relative to the number of patents already acquired and recent business development in terms of change in turnover. Financing additional technology-based business opportunities of any young DDLSF above a certain threshold value will jeopardise the venture capitalist's future returns on investment because of declining and ultimately negative changes in turnover of the young DDLSF.

4.7 Discussion

In this chapter, we have attempted to explain the extent to which dedicated life sciences start-ups engage in partnering. To do this, we attributed a central role to the possible sequence of events leading to overcoming the liability of newness, as defined by Stinchcombe (1965). This implies that we have focused on factors stimulating the visibility and reputation of the start-up. In doing so, we have also explicitly taken into account the relationships among the explanatory variables, which have been specified in other studies as independent variables. In other words, this chapter presents a dynamic model of subsequent activities and events leading to partnering by start-ups as opposed to a single static explanatory equation for partnering presented in the studies referred to below. Moreover, this enabled us to take into account the indirect effects among the variables in the model. Comparison of the direct effects in Figure 4.2 and the total effects in Table 4.4 shows that the estimated direct effects on partnering by young DDLSFs provide only a partial explanation and that the direct effects among the explanatory variables must also be specified on theoretical grounds in order to arrive at a more comprehensive explanation. In other words, not single, seemingly independent activities and events but sequences of activities and events determine the partnering rate of young DDLSFs. This outcome validates Niosi's conclusion (stated without direct statistical support) about the existence of such sequences of activities and events in the development of high technology firms (Niosi, 2003).

The results presented in this chapter support various effects found in other studies on partnering by high technology start-ups of Eisenhardt and Bird Schoonhoven (1996), Baum et al. (2000), Niosi (2003) and Baum and Silverman (2004), although these studies have only addressed direct effects between variables. A comparison of the results obtained in these studies and the results obtained here can be found in Table 4.5.

While Baum et al. (2000) found a direct positive reputation-related effect of patenting on the partnering rate of firms, we found such a reputation-related effect of patenting on partnering to be indirect, namely through venture capital acquisition. The direct effect of patenting on partnering is shown to be a negative, inducement-related effect. Apparently, DDLSFs engage in partnering because of the inducement to complement their own knowledge and competences and this need for additional competences decreases as the patent portfolio of the firm expands. Additionally, Eisenhardt and Bird Schoonhoven (1996) also found a significant effect of management team size on partnering but as a direct effect and not as an indirect effect through venture capital acquisition. Niosi (2003) also reports that venture capital acquisition and efficient R&D (reflecting current business development) depends on patent acquisition. Baum and Silverman (2004) also found a positive influence of patent acquisition on venture capital acquisition and a positive influence of management team size on venture capital acquisition. However, they did not assess the important role of both patent and venture capital acquisition in partnering by start-ups.

The results obtained here show that young DDLSFs are tempted to engage in partnering to obtain additional knowledge and attract partners by showing successful business development and successful venture capital acquisition. An additional explanation for the positive effect of venture capital acquisition on the partnering rate might be that such acquisition stimulates start-ups to initiate further development of their (patented) technological knowledge. While other studies have not found a significant effect of finance-related variables on partnering (Gulati, 1999; Ahuja, 2000), this study shows that the financial functioning of a start-up (i.e. initial business development) does play an important but indirect role in developing other resources that do affect partnering directly. The results thus indicate that an analysis of the partnering rate

Table 4.5 A comparison of the results obtained here and in other studies addressing partnering by high-technology start-ups

Direct effects found in other studies	**Results of this study**	
	Direct effects	**Indirect effects**
Number of patents → Partnering rate (+) (Baum et al., 2000)	Number of patents → Partnering rate (-)	Number of patents → Partnering rate (+)
Number of patents → Venture capital (+) (Niosi, 2003; Baum & Silverman, 2004)	Number of patents → Venture capital (+)	Number of patents → Venture capital (+)
Number of patents → Current business development (+) (Niosi, 2003)	Number of patents → Current business development (-)	–
Size management team → Venture capital (+) (Baum & Silverman, 2004)	Size of the management team → Venture capital (+)	–

of start-ups based on their resources can benefit from a dynamic, sequential conceptualisation. Moreover, this is also relevant for examining the development of firms' resource portfolios.

Whereas the Resource-Based View initially restricted opportunities of firms to the exploitation of current resources and development of new resources in-house (Wernerfelt, 1984), various recent studies have examined the option of sharing resources with other organisations shaped by the emergence of interorganisational collaborations (see for instance Ahuja, 2000). This study has substantiated this notion of resource sharing by indicating that technology development induces partnering, whereas business development generates opportunities for partnering. The mediating role of the size of the management team indicates that DDLSFs use this team to influence, and to some extent to possibly control their environment, as proposed by the resource dependence perspective (Pfeffer and Salancik, 1978; Lewin et al., 2004)[13].

Finally, a methodological note. The Chi-square based measures of fit of the specified model to the input data and the R^2 measures of the explained variance of dependent variables presented for Figure 4.2 show that Chi-square based measures of fit are not good indicators of the explanatory power of the models specified by the authors cited above. The probability of fit increased from 0.31 for the equation given in Table 4.2 to 0.96 for Figure 4.2 whereas the R^2 remained virtually the same for the partnering rate in the equation given in Table 4.2 and Figure 4.2, namely 0.63 and 0.62, respectively. Hence, the predictive power of the discrete regression equations estimated by the authors mentioned remains unknown. This problem has been overcome in this study by the statistical methods used.

4.8 Conclusion

The research question addressed in this chapter was: "*What resource stocks affect interorganisational partnering by young Dutch dedicated life sciences firms?*". To answer this question we focused on the relevance of effects of patent and venture capital acquisition. After specification and operationalisation of a theoretical model of these influences, the model was tested using appropriate statistical methods. The statistical results validate the theoretical model and 62% of the variance of the dependent variable 'number of collaborative relations' was predicted correctly. Partnering is influenced most by venture capital acquisition, less by prior business development and least by patent acquisition. Current business development and management act as important intermediary variables between patent acquisition and venture capital acquisition. This indicates the need of current patent exploitation for additional venture capital acquisition, which in turn stimulates partnering. Consequently, reputation-related effects of patent and venture capital acquisition play a very important role in partnering by dedicated life sciences start-ups aiming to achieve further business development and growth. With regard to venture capital acquisition, such reputation-related effects directly influence partnering, whereas with regard to patent acquisition these effects are indirect.

This study shows that not only taking into account the direct effects of explanatory variables on a dependent variable but also the indirect effects specified on theoretical grounds improves the explanation provided. Furthermore, incorporating these indirect effects in the statistical analysis of the explanatory model provides valuable insights into important management and financing issues concerning business development by start-ups in the life sciences industry.

Future research based on more refined indicators of the concepts used and/or additional explanatory concepts should focus on a further reduction of the 38% unexplained variance of partnering by start-ups. Also, future research should provide insight into the extent to which the effects found in this study are also valid in other populations of high technology start-ups, thereby producing some insight into the reliability of these effects[14].

5 Finding partners and the role of resource-based inducements and opportunities in R&D partnering

5.1 Introduction

In high technology sectors such as the life sciences, the pace of technological change and increasing complexity of successive technologies make it impossible for a single firm to possess all resources required to conduct R&D in-house (Powell et al., 2005). This results in a distribution of resources and capabilities across organisations within an industry. Access to complementary knowledge and resources then becomes pivotal, rather than actual acquisition of knowledge and resources (Grant and Baden-Fuller, 2004). The distribution of resources drives the emergence of networks of collaboration among high technology organisations with many lateral relations. We focus here on the case of partnering by Dutch dedicated life sciences firms (DDLSFs).

Over the past few decades there has been a vast increase in the number of interorganisational collaborations (Hagedoorn, 2002). This has resulted in an increase in the number of studies searching for explanations for this development. Some of these studies have addressed the relation between different firm-level (resource-related) variables and the propensity to partner (Eisenhardt and Bird Schoonhoven, 1996; Ahuja, 2000), while others have devoted attention to explaining whether or not a dyadic relationship is formed based on a combination of the characteristics of both partners (Gulati, 1995; Mowery et al., 1998). These studies have mostly attempted to find causal explanations for partnering. Other studies have attempted to provide initial insights into motives and objectives for engaging in partnerships (Hagedoorn, 1993; Bayona et al., 2001; Miotti and Sachwald, 2003; Yasuda, 2005), while some additional studies have related such motives to the organisational structure chosen for the partnership (Smith Ring and Van de Ven, 1992; Hagedoorn and Narula, 1996; Das and Teng, 2000). Finally, recent studies have been aimed at unravelling the explanatory factors of partnership performance and its contribution to firm performance (Stuart et al., 1999; Baum et al., 2000; Belderbos et al., 2004; Arend and Amit, 2005).

Building on this work we aim to provide insights into motives of organisations for establishing R&D partnerships with a specific partner, and the process of partner search and selection that follows. The main contribution of this chapter is to provide a more in-depth exploration of search and selection processes; processes which have largely been neglected in prior literature on partnering. From a resource needs perspective, the rationale behind this is that when formulating new objectives for development, organisations identify a need for certain resources, to which access is sought externally. These new objectives for development then also become starting points of the objectives of the partnership to be formed, and these needs constitute the motives for this formation with a certain specific partner organisation. In this respect, motives for partnering can be conceived as giving direction to the partnership formation process as they are based on the resources required from a potential partner and therefore determine the resource portfolio of the partner as desired by the focal firm. While some empirical studies have paid attention to variables explaining partnership formation on a dyadic level, such as relative prior network positions (Gulati, 1995) and the extent of technological overlap of organisations (Mowery et al., 1998) or their cognitive distance (Nooteboom et al., 2007), these studies only provide indirect insights into partner selection processes or motives of each partner that jointly influence the outcome of these selection processes. A study conducted by Uzzi (1997) provided a more in-depth view of the role of embeddedness of relationships in the formation of new relationships. In this chapter we focus on resource-based inducements and opportunities for partnering (Ahuja, 2000; Sakakibara, 2002), and the subsequent processes of partner search and selection resulting in partnership formation. In this respect, inducements for partnering represent the asset that is sought, whereas the processes of search and selection describe *how* this asset is sought. Our central research question is then the following:

Which inducements and opportunities guide interorganisational R&D partnering of Dutch dedicated life sciences firms and in what ways do these firms search for partners?

By answering this research question we aim to contribute to existing literature in two ways. First of all, we build on the Resource-Based View of the firm (RBV) by specifying an additional effect of resources other than contributing to the comparative advantage of the firm, namely that resources provide a firm with inducements and opportunities for partnering. Other studies have also looked into the role of resources as inducements and opportunities for partnering on the level of the firm (Ahuja, 2000; Meeus et al., 2001; Sakakibara, 2002; Meeus et al., 2004). We further unravel the role of these inducements and opportunities in the formation of individual partnerships, and more specifically in guiding the search for partners. Secondly, adding to the work of Smith Ring and Van de Ven (1994) on the formation and evolution of partnerships, we specify the different kinds of search mechanisms organisations can employ to find partners.

The theoretical framework is discussed in the following section. In Section 5.3, the operationalisation, method of data collection and analysis are elaborated on, followed by an overview of the results obtained in Section 5.4. Sections on discussion and conclusion end this chapter.

5.2 Theoretical framework

This section elaborates on the theoretical notions applied in this chapter. We build on the Resource-Based View of the firm, in which a firm is perceived as a bundle of resources which are defined as “those (tangible and intangible) assets which are tied semi permanently to the firm” (Wernerfelt, 1984: p. 172). The main focus of a firm is then on the exploitation of existing resources and simultaneously on the development of new or improved resources to ensure future possibilities for exploitation (Wernerfelt, 1984). The heterogeneity of resources across firms is the main cause of differences in the competitive advantage of these firms. In this respect, the RBV represents a relatively internalistic view on explaining firm behaviour. Building on this Resource-Based View of the firm, the Resource Dependence perspective acknowledges that firms’ heterogeneous resource portfolios inherently make them dependent on one another for gaining access to specific resources (Pfeffer and Salancik, 1978). These dependencies are shaped by all sorts of interorganisational resource exchange relationships that emerge over time. To further elaborate on the ideas of the resource-based view of the firm, we continue by addressing the role of inducements and opportunities for partnering in giving direction to the process of searching for partners. Also, possible ways of conducting this search are discussed. Finally, we address possible influences of patent acquisition on aspects of the process of partnership formation.

5.2.1 Motives for partnering with a specific partner: inducements and opportunities

As was stated by Van de Ven (1976): "the end objectives of organisations involved in an IR (ed.: interorganisational relationship) is the attainment of goals that are unachievable by organisations independently" (p. 25). Such unachievable goals may vary widely, including for instance conducting basic research on a specific subject or developing products to penetrate a new market segment. One frequently used explanation for the existence of such unachievable goals is the lack of certain resources to achieve them. In this respect, a lack of resources constitutes the motive for partnering with another organisation in order to enable achievement of a goal. The objective of the partnership and the motives of an organisation for partnering are then distinct aspects. Some studies have focused on more general motives for collaboration, such as reducing the time to market and maintaining flexibility (Nooteboom, 1999; Hagedoorn, 2002). While such motives can be useful in explaining whether an organisation decides to 'make or buy', the resource needs underlying these general motives (such as the need for a specific resource in order to reduce the time to market) actually give direction to the process of partner search and selection. There is thus an important distinction between the overall objective(s) of a partnership and each partner's motives for engaging in this partnership.

The heterogeneity of resource portfolios of firms is the main reason for resource-based partnering. This heterogeneity results in the existence of complementarity between firms active in the same technological field. Whereas the Resource-Based View originally only accounted for the exploitation of existing resources and in-house development of new ones to ensure possibilities for exploitation in the future (Wernerfelt, 1984), recent studies on firm behaviour have indicated the possibility of firms to share (access to) resources by establishing collaborative relationships with other organisations (Ahuja, 2000; Grant and Baden-Fuller, 2004). In this respect a resource needs perspective, implying that firms engage in collaboration with other organisations to fulfil their needs for certain resources, has been frequently stressed. Such a perspective will also be adhered to here.

Addressing partnering from a resource needs perspective implies that a focal organisation (ego), after identifying a resource need of a certain kind, starts searching for an appropriate partner (alter). The primary factor that determines the appropriateness of alter is the extent to which it is able to fulfil the resource needs of ego, hence alter should offer complementary resources. This implies that these resource needs of ego give direction to the process of searching for partners. The ability of another organisation to fulfil a resource need of this focal firm provides it with *opportunities* for partnering (Ahuja, 2000). On the other hand, to become receptive to ego's invitation, such an alter should also have some kind of inducement for partnering with ego, as the benefits should at least to some extent be mutual. The parts of the resource portfolio of the focal firm making it an attractive partner constitute its opportunities for partnering. This results in an overall perspective in which both partners have certain inducements for partnering, and their opportunities for partnering are, at least to some extent, a reflection of each other's inducements (inducement ego = opportunity alter), as is depicted in Figure 5.1. The extent to which 1) both organisations have strong inducements for partnering; 2) these inducements of ego can be fulfilled by alter and vice versa; and 3) these inducements and opportunities derive from a clear, perhaps even common objective of the partnership, may be expected to influence each partner's commitment to the partnership.

Now, how do these inducements and opportunities relate to the search for partners? When perceiving partnering as based on such inducements and opportunities for partnering with a specific partner, it may be expected that, at least for ego, inducements 'come first'. The process of partnership formation then begins with an ego that searches for a partner that is able to fulfil its resource need. In this respect, the alter becomes involved in the partnership primarily because of an opportunity offered by induced partner ego. But for alter to commit to the partnership as well, this organisation also needs to gain something out of the partnership, constituting its inducements for partnering, which may be considered to *emerge* after being asked to collaborate by ego. Overall, the inducements for partnering of ego may be considered to primarily *drive* the establishment of the partnership while its opportunities *enable* it to make other organisations interested in partnering with them.

In Figure 5.1, motives of ego and alter that are of importance in partnership initiation are related to one another. It is important to note that the DDLSFs studied here can take up the role of either ego or alter, in each of their partnerships.

Next to partnerships formed according to the process depicted in Figure 5.1, where an ego and an alter can be discerned and partnership formation is initiated after ego has identified a resource need, partnerships can also be formed jointly by partners that are already in close contact with each other, for instance because they have already collaborated previously. This option will also be taken into account in Section 5.2.2 on partner search and selection.

To further clarify, the inducements and opportunities for partnering are distinct from the actual general objective of the partnership established. While such objectives may also be considered 'opportunities', for instance they could be opportunities for further business development, they are not *opportunities for partnering* since they do not enable partnering but are a reason/rationale for partnering. As stated by Ahuja (2000): "linkages are only formed

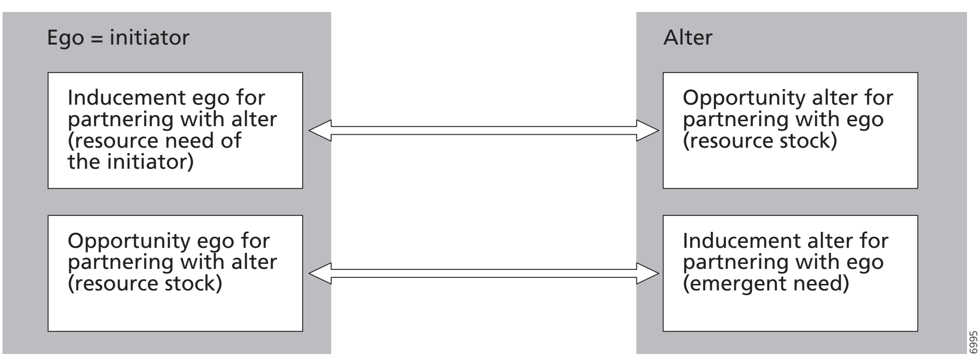

Figure 5.1 The relation between motives of partnership formation of ego and alter

when actors with inducements are successful in finding collaboration opportunities" (p. 318). The existence of such collaboration opportunities then depends on the extent to which other organisations within the environment of the firm are able to fulfil the resource needs of the focal firm. Also, resources that the focal firm can contribute to the partnership and that make the partnering organisation decide to collaborate with this DDLSF and not with another potential partner are of importance here.

So far, several studies have analysed partnering behaviour (rates) on the level of the firm, and therefore have taken into account resource-related variables as independent variables and variables reflecting partnering behaviour as dependent variables (Eisenhardt and Bird Schoonhoven, 1996; Ahuja, 2000; Sakakibara, 2002). In such analyses, which are often of a cross-sectional nature, negative effects of resource stocks-related variables on partnering rates are interpreted as inducements for partnering whereas variables with positive effects are interpreted as opportunities. While such analyses have provided useful insights into resource-related motives of partnering, they do not provide insight into the influence of, for instance, the content of the technology portfolio and, in view of this, the technological specificity of partnering may not be sufficiently revealed by such studies in which (technological) resources are quantified.

Some other studies have employed a dyadic perspective, linking certain resource-related characteristics of ego to the characteristics of alter. Previous research on the formation of R&D partnerships considered the importance of technological complementarity in partnership formation. Different notions have been addressed that relate to technological complementarity. These include technological overlap (Mowery et al., 1998) and cognitive distance (Nooteboom et al., 2007). These studies have mostly found an inverted u-shaped relation between these technological complementarity-variables and the propensity of two organisations to partner. A certain extent of similarity of knowledge is thus required to enable organisations to benefit from mutual access to the other's dissimilar knowledge. Technological complementarity is only one possible resource-related source of complementarity. Such complementarities can also occur within, as well as across other types of resources (Teece, 1986). As stressed by Stoelhorst (1997), a firm's 'resources' include its purpose (ideology), competences (technology), capabilities (coordination/management) and assets (ownership). In this study, we focus on the last three by making a distinction according to different *fields of knowledge* that are considered to be of importance, including technology, commercialisation and management. Assets as discerned by Stoelhorst (1997) relate, for instance, to networks for the distribution of products (commercialisation-related resource) as well as facilities for research and patents (technological resources). Whereas technological resources may be considered to be most important when inducements for partnering of high technology firms are studied, resources related to commercialisation are also taken into account here.

These inducements and opportunities for partnering could differ for DDLSFs that are relatively unestablished and DDLSFs that are relatively established, as these firms may have accumulated different resources in-house and may be in need of different resources to be accessed externally. Also, as this represents a highly important resource to technology-based firms, patent acquisition could influence these inducements and opportunities for partnering. For instance, patents have been thought to induce the commercialisation of a patented invention (Mazzoleni and Nelson, 1998), possibly making inducements for collaboration more commercialisation-oriented. Finally, we also make a distinction in the results section between inducements and opportunities of DDLSFs in partnerships with other firms and those with research institutes.

5.2.2 Searching for and selecting potential partners

How do organisations find partners? Based on inducements for partnering, an organisation starts searching for appropriate partners within its environment. Assuming that organisations with complementary resource portfolios exist within a firm's environment (and thus opportunities for collaboration exist), an important aspect is being able to identify these organisations. In this respect, it is important that a focal firm has information on promising organisations within its environment with whom it could establish a partnership (Gulati, 1998). We discern several ways in which focal organisations can find partners: based on the focal organisation's internal knowledge, directly or indirectly through contacts of the organisation, or at events, such as conferences. Also, when wanting to be invited to engage in collaboration, a firm should be visible to such induced partners. All these pathways are in fact paved with the organisation's social capital.

The extent to which potential partners can be found is influenced by the number of organisations the focal firm has sufficient information on to be able to determine its appropriateness as a partner. In order for other organisations to be able to find the focal organisation, the visibility of this focal organisation within its technological field or industry is decisive. Both effects help to increase an organisation's ability to utilise opportunities for partnering within its environment (Ahuja, 2000). As was proposed by Smith Ring and Van de Ven (1994) social capital has the potential to shorten the steps in the process of alliance formation given that increased level of trust associated with partnering with partners known to the organisation decreases relational risk, e.g. risk introduced by the possibility of opportunistic behaviour exerted by the partner (Das and Teng, 1998; Ahuja, 2000).

Obtaining an overview of an industry (and promising organisations therein) and becoming visible to other organisations within an industry depends on how well a firm is embedded in business contact networks. While factors related to a firm's embeddedness within its environment are important, given that they enable the firm to find partners, the complementarity of resources across organisations may be expected to be more decisive; as Gulati (1998) states: "firms don't form alliances as symbolic social affirmations of their social networks, but rather, base alliances on concrete strategic complementarities that they have to offer each other" (Gulati, 1998: p. 301).

In general, empirical studies on the influence of an organisation's social capital on partnership formation have related proxies of the stock of social capital to the partnering rate of the firm (Eisenhardt and Bird Schoonhoven, 1996; Ahuja, 2000; Sakakibara, 2002). These studies however hardly address the impact of specific aspects of social capital on the actual choice of a specific partner. Some studies that have linked aspects of social capital to the likelihood of partnership formation between two organisations were focused on relating the network position of these two organisations to subsequent partnership formation (Stuart, 1998; Gulati, 1999). While those studies do provide direct insights into the influence of network positions on partnering, they mostly take into account only one type of network, namely the network of partnerships at t =-1. However, the network of contacts of a focal firm consists of many different organisations (or individuals belonging to the organisations) with whom the focal firm (or the managers/researchers of the focal firm) can have various types of relationships, ranging from friendship ties to relationships based on a previous collaboration between the two organisations. Relationships of this kind can lead to the formation of new partnerships, indirectly as well as directly. Indirectly, such contacts can inform the focal firm about potential partners based on additional information on other organisations that is available to the focal firm (Gulati, 1998). Directly, the focal firm may establish a collaborative relationship with such a contact. In the event that such a contact was originally based on a previous collaborative relationship, initiation of a new collaborative relation results in the formation of a repeated tie. But as already explained in the foregoing, given that the original type of relationship between the focal firm and such a contact can vary, repeated collaboration is only one possible outcome of partnership formation with a direct contact.

In this study we aim to address how two partners can meet one another in a more open-ended, exploratory manner. For instance: participating in events such as conferences and workshops is a more 'coincidental' way of finding potential partners. Additionally, a more deliberate way of finding potential partners is by making use of an organisation's internal knowledge, for instance on a specific technological field or market. Public sources of knowledge, such as patent databases can be used to complement this knowledge internal to the firm. The exploratory nature of this study enables us to reveal the importance of such other ways to find new partners.

Processes of partner search and selection can differ for firms with different characteristics. For instance, the extent to which DDLSFs initiate the formation of a partnership can differ for DDLSFs that have acquired a patent and those that have not. This possible difference is thought to be related to the commercialisation-inducing effect exerted by patent acquisition (Mazzoleni and Nelson, 1998), implying that those firms that have acquired a patent could be more inclined to take the initiative in forming partnerships than firms that do not have patents. Moreover, since patent acquisition improves a firm's negotiating position (Thumm, 2004), DDLSFs that have acquired a patent could be more inclined to consider several partners. Such differences may also appear for relatively unestablished DDLSFs and relatively more established DDLSFs, and for partnerships with other firms and research institutes. We will explore these differences in the results section.

In summary, three aspects may be considered as having an influence on search and selection processes, namely: inducements, opportunities and the availability of information. The latter depends to a large extent on the embeddedness of the organisation in contact networks.

We aim to specify the inducements and opportunities for partnering of DDLSFs and partner search processes, as well as to explore the possible differences in these aspects between DDLSFs that have acquired patents and those that have not, between relatively unestablished and relatively established DDLSFs, and between partnerships with other firms and partnerships with research institutes. In the following section, the data collection and measurement methods applied are discussed.

5.3 Research methods and operationalisation

The total population of Dutch dedicated life sciences firms comprised some 160 firms at the end of 2005. In order to gather the data required for this study, in-depth face-to-face interviews were necessary, as the aim was to provide insights into the process of search and selection prior to

Table 5.1 Number of employees and age of the firms included in this study; Firms that have not acquired patents are shown in italics

	Firm size 2005 < 10 fte	Firm size 2005 > 20 fte
Firm age (2005) < 4 years	*DDLSF 1 (2004)* *DDLSF 4 (2003)* DDLSF 2 (2003) DDLSF 6 (2002) DDLSF 5 (2002)	
Firm age (2005) > 4 years	DDLSF 3 (1999)	DDLSF 7 (1993) DDLSF 8 (2000) *DDLSF 9 (1988)*

partnering. Such information cannot be obtained by using written questionnaires. Because this method of data gathering was used we were forced to make a selection among firms active in the sector. Given the exploratory nature of this study, making a selection was considered justifiable. We started out by discerning firms according to their resource endowment and rate of partnering. Subsequently, due to the focus in this chapter on the influence of patenting on partnership formation, we also made sure to include firms both with and without patents. Overall, nine interviews were held with the managers[15] of nine DDLSFs. Six of these had patents while the remaining three did not. Table 5.1 provides information on the characteristics of these firms. In order to ensure confidentiality, these firms are referred to here as DDLSF 1 to 9.

As can be seen in Table 5.1, some of the firms included in this study were only founded a few years ago while others are older. As could be expected, for most firms the size of the firm (measured by the total number of full time equivalent employees) is related to its age. In general, young firms are small, while older firms are larger. Figures 5.2 and 5.3 provide an overview of the frequency distributions of both firm age and firm size. The data used to compile these graphs were obtained from a written questionnaire distributed on behalf of the Dutch BioPartner Network, a government initiative established in order to stimulate the founding of new firms in the life sciences. The data applies to the year 2005, and the response rate of this survey was about 43%.

By comparing the age and size of the nine firms studied here to the frequency distributions of these variables in the population of DDLSFs given in Figures 5.2 and 5.3 it can be concluded that several of the firms of which the managers were interviewed are relatively large with regard to their number of full time equivalent employees (DDLSFs 7 to 9), while others are relatively small (all others). Also, some firms have already been in existence for a relatively long period of time (DDLSFs 7 and 9) while others are relatively new (DDLSFs 1, 2 and 4). In order to determine whether these differences with regard to firm size and age among the firms included in this study influence findings on inducements, opportunities and search, these differences are explicitly addressed in the results section.

Overall, based on values of the different firms for firm age and firm size, more established firms include DDLSFs 7 to 9, while all other firms may be considered less established. These less established firms also include DDLSF 3, which, based on its age, would be considered more established, but as it is still very small it is attributed to the group of less established firms within the field of life sciences. It must be noted here that when compared with other more

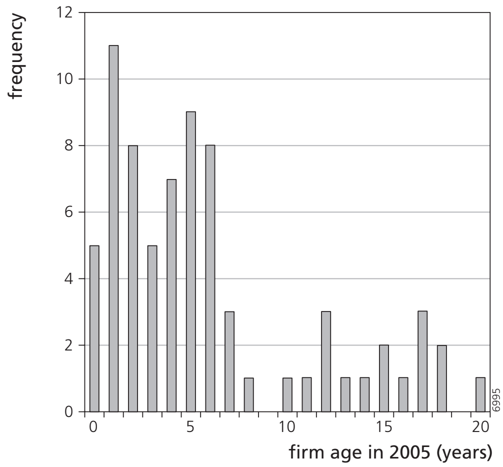

Figure 5.2 Frequency distribution of firm age of DDLSFs in 2005 (N=73)

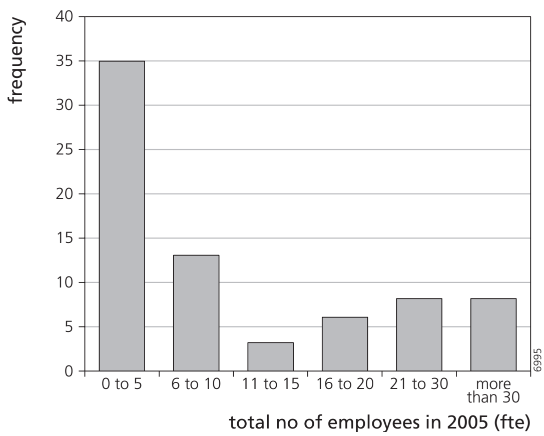

Figure 5.3 Frequency distribution of the total number of employees of DDLSFs in 2005 (N=73)

established populations of dedicated life sciences firms, those firms that are considered to be more established here might also be regarded as start-ups when compared to other firms in such established populations. However, taking into account the frequency distributions given in Figures 5.2 and 5.3, and the characteristics of the firms studied here given in Table 5.1, it is justifiable to refer to the three largest (and relatively older) firms as 'more established'. This distinction between the firms studied will be used in the results section.

The main focus in the interviews held was on the most important partnerships the firm is currently engaged in with another firm and a research institute. All firms were engaged in partnerships with other firms, while 7 out of 9 firms also collaborated with knowledge institutes. Conducting these interviews thus provided us with results on the formation processes of 16

R&D partnerships. In retrospect, questions were asked on the processes of search and selection. The interviews were semi-structured, i.e. some questions were open-ended and others were relatively more closed. For example, the interviews started with some general, open questions on who were partners of the firm and how the firm usually finds partners. These questions were followed by more structured and closed questions on the characteristics of their most important partnerships, such as the extent to which different resource-based motives (inducements and opportunities) had been of importance in their formation. The manager of the DDLSF was also asked questions on inducements of the partner organisation (constituting the DDLSF's opportunities for partnering). These inducements must therefore be regarded as the partner's inducements *as perceived by the focal firm.*

As the objective of this study was to provide insight into inducements and opportunities for partnering and finding partners, questions asked during the interviews focused on these subjects. Table 5.2 provides an overview of the operationalisation of each of the subjects/concepts discerned in the theoretical framework.

Table 5.2 Operationalisation of concepts/issues

Concepts/ issues	**Operationalisation**
Inducements for partnering	Managers were asked to indicate on a scale of 1-10 whether the following resource-related inducements for partnering on R&D were relevant in choosing this specific partner: obtaining access to: 1) technological knowledge; 2) facilities; 3) knowledge of the market; 4) market entry; 5) knowledge related to management; 6) knowledge on regulatory affairs; 7) other resources. After grading the importance of these inducements on a scale of 1-10, the managers were asked to rank the inducements that were considered to be of importance (only 1st, 2nd and 3rd).
Opportunities for partnering	Managers were asked to indicate on a scale of 1-10 whether they thought the following resource-related inducements for partnering were relevant to their specific partner in choosing to collaborate with them: obtaining access to: 1) technological knowledge; 2) facilities; 3) knowledge of the market; 4) market entry; 5) knowledge related to management; 6) knowledge on regulatory affairs; 7) other resources. After grading the importance of these inducements on a scale of 1-10, the managers were asked to rank the inducements that were considered to be of importance (only 1st, 2nd and 3rd).
Finding partners	Managers were asked how the very first contact with this partner was established. From the answers given to this question it was possible to derive: 1) who was responsible for the establishment of this first contact; and 2) which sources of knowledge were used to find the partner. It was attempted afterwards to subdivide the sources mentioned into: 1) through the network of contacts of the firm; 2) by using knowledge of the field internal to the firm; and 3) (relatively coincidental) meetings at events.
Extent of selection	Managers were asked to indicate whether or not other potential partners were also considered. If not, it was asked whether or not he or she thought it would have been possible to carry out this project had the partner been another organisation.
Establishedness	In order to determine the relative establishedness of the firms included in this study their age and size were compared to the age and size of other DDLSFs. Relatively unestablished firms have less than 10 employees (fte) and have been in business less than four years, whereas firms with more than 20 employees (fte) and in business for more than four years are considered more established within the sector. This distinction was made with Figure 5.2 in mind.

In order to analyse the data obtained in the interviews we make use of the categories belonging to the different concepts given in Table 5.2. By making cross tables we aim to find relations between types of DDLSFs (established/unestablished, with/without patents) and these different concept categories.

5.4 Results

The results obtained will be discussed in this section. We start with a general overview of the partnering behaviour of the nine firms studied by discussing inducements and opportunities at the level of the firm. Subsequently, we move on to give a more detailed description of the characteristics of the 16 individual partnerships followed by the inducements and opportunities of relevance to the DDLSF in establishing these partnerships. Also, the processes involved in finding partners will be described. In providing these descriptive results, we distinguish between partnerships of DDLSFs with research institutes and partnerships with other firms. Finally, we relate the aspects of inducements, opportunities and partner search and selection to characteristics of the DDLSFs involved. The characteristics taken into account here have already been mentioned in Section 5.2 and include whether the DDLSF can be considered relatively unestablished or established, and whether or not the DDLSF has acquired a patent.

5.4.1 General overview of partnering: the level of the firm

Table 5.3 shows whether each of the nine firms studied mainly acts on inducements or opportunities for partnering or both, as well as how these inducements and opportunities are acted on. This latter information is contained in the corresponding cell.

Table 5.3 shows that four firms stress inducements, while two others stress opportunities. Three firms indicate a mix of both. Sources of information on potential partners used by organisations in searching for partners include patents, internal knowledge of the market, networks of contacts of the firm (managers as well as employees) and knowledge of advisory board members. Attending events such as symposia and conferences is mentioned by several managers of established as well as relatively unestablished firms as an important means of finding partners and improving the visibility of the firm to other organisations.

The primary needs of firms acting on their inducements directly derive from resources (including specific knowledge) needed to achieve their own development (DDLSF 8) or commercialisation trajectories (DDLSFs 3 and 4). Also, short-term exploitation of service-related activities is of importance in this respect. Both DDLSF 2 and DDLSF 7 stated that they had very few partnerships with other firms in which both organisations are equal partners. These firms often supply contract research or pay their partner to do so.

When comparing the partnering behaviour of relatively unestablished firms (DDLSFs 1 to 6) with more established firms (DDLSFs 7 to 9) we find that most established firms employ a mixture of inducements and opportunities for partnering, whereas unestablished firms are inclined to stress either inducements or opportunities. More established firms seem to be interested in taking up opportunities for partnering offered to them by others, but are themselves also actively searching for promising partners. Several relatively unestablished firms do not seem to have many opportunities for partnering offered to them, while two other unestablished firms indicate that they are almost totaly dependent on such opportunities. These firms that make

Table 5.3 General inducements and opportunities for partnering of DDLSFs (N=9) and the associated search processes; the source of knowledge on promising partners used is given between brackets, with: IK = internal knowledge; NW = using the network of the firm; and EV = by participating in events

DDLSF No.	Inducements	Opportunities	Mixed
1	• scouting of professors • searching for buyers (source of knowledge unknown)		
2	• patent search (IK) • network of the firm (NW) • national and European industry organisations (NW)		
3	• need for market and scientific partner: searching through the manager's network (NW)		
4	*(In the future: knowledge on promising applications of technology (IK))*	• trust expressed by potential partner, no reputation yet	
5	*(In the future: to exploit services)*	• leading edge knowledge (patents) • reputation of one of the founders and managers	
6			• the firm's network (NW)
7			• conferences (EV) • scientific advisory board (NW)
8	• knowledge of the market (IK)		
9			• knowing what would fit (IK) • partly from the firm's network (NW) • symposia (EV)

use of opportunities have markedly different reasons for doing so. One of the firms (DDLSF 4) indicated that because it did not have a reputation as yet, it could only depend on the opportunities for partnering offered to them by other organisations that for some reason were interested in partnering with them. While the other firm may also be considered a start-up by its age and size, its leading-edge patents and well-known researcher have so far provided this firm with plenty of opportunities for partnering. These two firms both indicate that they will focus more on their own inducements for partnering in the near future; one of them in order to find customers for commercialisation of its service activities, the other to find partners working on promising applications of its technology.

5.4.2 General characteristics of individual partnerships

In this section the characteristics of the 16 individual partnerships (7 with research institutes, 9 with other firms) are discussed. These partnerships all focus on some part of a product or process development trajectory. In some cases, the partnership covers the whole development trajectory, while in other cases the partnership merely consists of a contract research related activity conducted by one partner and contributes to the development trajectory of the other partner.

Table 5.4 Subject and origin of the partnerships studied (N=16)

	Partnerships with research institutes; origin:			**Partnerships with firms; origin:**		
	DDLSF	**partner**	**joint**	**DDLSF**	**partner**	**joint**
Development of therapeutics and vaccines	DDLSF 2		DDLSF 1 DDLSF 4		DDLSF 2 DDLSF 4 DDLSF 5 DDLSF 7	DDLSF 1
Development of diagnostics	DDLSF 7		DDLSF 5	DDLSF 6		DDLSF 3
Process development, including technology platforms			DDLSF 9			DDLSF 8 DDLSF 9
Other	1 (very broad project DDLSF 3)			-		

A subdivision can be made between partnerships that primarily originate from the DDLSF, its partner or were formulated by the DDLSF and its partner in joint discussion. These data are given in Table 5.4.

Especially the development of medicinal products generates profits in the long term only. This is due to lengthy development trajectories. Diagnostics and processes may take less time to develop commercially. Five out of nine partnerships with other firms focus on medicinal product development, four of which originate from the partner. Only one interfirm project originates from the DDLSF and this project is aimed at the development of diagnostics.

Projects originating from either the DDLSF or the partner (i.e. projects that are not jointly established) differ somewhat in the extent to which the partners involved share performance risk of the project evenly (as defined by Das and Teng (1998)), ranging from clear-cut contract research agreements (the projects of DDLSF 2 and DDLSF 7) to more complicated and extensive milestone contracts (partnerships of DDLSF 4, DDLSF 5 and DDLSF 6 with other firms).

5.4.3 Inducements and opportunities for collaboration with a specific partner

Table 5.5 provides an overview of resource-related inducements of partnership formation by DDLSFs[16]. Columns 2 to 5 provide information on the extent to which the inducements defined in the first row of the table are considered to be of importance by either the DDLSF or the partner. From the perspective of the DDLSF, the inducements of its partner constitute its own (perceived) opportunities for partnering.

While this was questioned separately in the interviews, it appeared to be difficult for the managers to distinguish between the motive 'technological knowledge' and 'facilities'. In Table 5.5, these inducements are grouped, as are the different inducements related to knowledge on aspects of commercialisation. The two remaining categories of inducements include 'finance' and 'other'. While obtaining finance was not addressed explicitly in the interviews, managers indicated several times that this was relevant to the formation of the partnership. It is therefore included as a separate column.

It is important to note that for each of the partnerships studied, managers of the DDLSFs concerned were able to indicate their own primary inducements as well as those of the partner, as perceived by them. This implies that a certain extent of reciprocity of inducements for partnering

Table 5.5 Ranking of Inducements and opportunities of DDLSFs for engaging in partnerships; inducements of the partner = opportunity DDLSF; * = inducement initiator

Partnerships with research institutes DDLSF no.		**Technological knowledge/ facilities**	**Knowledge on aspects of commercialisation (marketing, management etc.)**	**Finance**	**Other**
1	DDLSF	1st			
	Partner		1st		
2	DDLSF	1st * 2nd*			3rd: Network of partner*
	Partner	3rd	2nd	1st	
3	DDLSF	1st*			
	Partner	1st	2nd		
4	DDLSF	1st			
	Partner	2nd*	1st*		
5	DDLSF	2nd			1st: personal interaction
	Partner	1st (incl IP)* 2nd*	3rd*		
6		–	–	–	–
7	DDLSF	1st* (access to patients)			
	Partner	1st		2nd	
8		–	–	–	–
9	DDLSF	1st			
	Partner	1st	1st		
Partnerships with other firms DDLSF no.					
1	DDLSF	1st 2nd	3rd		
	Partner		1st incl. obtaining grants		
2	DDLSF			1st	2nd: Technology development
	Partner	1st* 2nd*			3rd: Network DDLSF*
3	DDLSF		1st		
	Partner	1st (incl IP)	2nd		
4	DDLSF	1st			
	Partner	1st*			
5	DDLSF	2nd	3rd	1st	
	Partner	1st (IP)*			
6	DDLSF	3rd*	1st* 2nd*		
	Partner	1st (incl IP)			2nd: Reputation/network DDLSF
7	DDLSF			1st	1st: PR
	Partner	1st*			
8	DDLSF	1st (IP) 2nd*	3rd*		
	Partner	3rd	1st 2nd		
9	DDLSF		1st		
	Partner	1st	2nd		

was clear to them. The overall view of inducements leading to partnership formation of DDLSFs with research institutes is relatively straightforward: DDLSFs collaborate with these partners to access technological knowledge and facilities, especially related to biology and pharmacology. Other inducements are hardly relevant. Research institutes engage in partnering with DDLSFs to obtain access to technological knowledge and also for more commercialisation-related inducements (knowledge of markets as well as access to markets). Management skills and finance are also of importance to these research institutes.

Inducements of DDLSFs that play a role in the selection of other firms as partners are more diffuse: access to technological knowledge as well as market-related motives are relevant in this respect. Moreover, partnering with other firms also constitutes a source of access to financial resources for DDLSFs. Such partnerships may thus be perceived as a means for a DDLSF to commercialise technology. In partnerships with research institutes, resource complementarity mainly implies complementarity of technological resources (including facilities), while partnerships with other firms are often based on complementarity across different types of resources, suggesting, for instance, the exchange of access to technological knowledge and financial resources.

What can also be derived from Table 5.5 is that in most cases the initiator ('ego' in Figure 5.1) of the partnership is looking for complementary technology and/or facilities (4/5 of partnerships with research institutes that were not jointly initiated, the partner of DDLSF 4 is also interested in its knowledge related to marketing; 5/7 partnerships with firms that were not jointly initiated). The remaining two partnerships with firms (of DDLSF 3 and DDLSF 6) are aimed at the commercialisation of patents owned by the DDLSFs involved. These DDLSFs are primarily engaged in partnerships with these firms in order to obtain access to a market and knowledge of a market as the DDLSFs involved do not have that knowledge in-house. In three partnerships with other firms, the DDLSFs involved primarily engage in the partnership to obtain financial resources. These three firms all have patents.

In three cases (one partnership with a research institute and two with firms) the managers of the corresponding DDLSFs indicated that gaining access to the partner's networks of contacts was another incentive for either the DDLSF or its partner to engage in the partnership. However, gaining access to such networks of contacts was not the primary inducement for collaboration with a specific partner in any of these three cases (in two cases it represents the third most important inducement, in one case the second).

5.4.4 The search process: ways of finding partners

Table 5.6 provides an overview of several aspects of the search process, including which of the partners conducted the search and selection, and the way in which the partner was eventually found. Again, a subdivision is made between partnerships of DDLSFs with research institutes and with firms.

As can be derived from this table, in some cases the search was conducted by the DDLSF, whereas in other cases the search was conducted by the partner. While we know from asking the manager of the DDLSF how they were found by this partner, this manager generally does not have insight into the actual process of partner selection possibly conducted by the partner. Only in one case were we able to ascertain that the DDLSF was selected by the partner from multiple potential partner organisations (partnership of DDLSF 4 with another firm). In several other

Table 5.6 The process of partnership formation (N=16); IK: internal knowledge; DNW: directly with a contact of the firm; INW: indirectly through the network of contacts of the firm; EV: at events. '(partner)' indicates that the search behaviour of the partner can be classified as such

Partnerships with research institutes DDLSF no.	**Origin project**	**Searcher**	**Method of finding partner**				**Others considered?**	
			IK	**DNW**	**INW**	**EV**	**Yes**	**No**
1	Joint	-(3rd org)			(3rd org)			*
2	DDLSF	DDLSF		*			*	
3	Joint (broad)	DDLSF				*		*
4	Joint	partner		(partner)				*
5	Joint	partner	(partner)					*
6	–	–	–	–	–	–	–	–
7	DDLSF	DDLSF	*					*
8	–	–	–	–	–	–	–	–
9 (Repeated tie)	Joint	–						*
Partnerships with firms DDLSF no.								
1 (Repeated tie)	Joint	–						*
2	Partner	Partner		(partner)				*
3	Joint	DDLSF			*			*
4	Partner	Partner				(partner)	(partner)	*
5	Partner	Partner	(partner)				*	
6	DDLSF	DDLSF		*			*	
7	Partner	Partner		(partner)				*
8	Joint	DDLSF			*		*	
9	Joint	–		*				*

cases, the manager of the DDLSF indicated that their partner might have considered other organisations for collaboration in the partnership. Because of this, we focus primarily on the role of the DDLSFs involved when selection is addressed.

The initiation of partnerships, finding partners/being found by partners and selection among potential partners will be discussed in the following paragraphs. We will conclude with a separate discussion of partnership formation in jointly initiated partnerships.

Initiation of the formation of partnerships

In three out of seven partnerships of DDLSFs with research institutes the partnership is initiated by a searching DDLSF, while in two cases the partnering research institute takes the initiative. In the two remaining cases, the organisation that searched for partners was neither the DDLSF nor the research institute, but in one case a third partner initiated the partnership. In the other case the partnership was initiated jointly.

Where partnerships of DDLSFs with other firms are concerned, the formation of four of the nine partnerships was initiated by a searching partner, whereas the formation of three was initiated by a searching DDLSF. The two remaining partnerships were jointly initiated.

Finding partners and being found
As is shown in Table 5.6, in six cases a DDLSF initiated the formation of a partnership by searching for a partner (three times in partnerships with research institutes, three times in partnerships with firms). In four cases, they found their partners through the network of the firm's contacts (all partnerships with firms, twice indirectly, once directly and one of the partnerships with a research institute, directly), whereas in the remaining two instances other sources of information were considered. In one case the DDLSF knew the partner was *the* expert in a relevant knowledge field (DDLSF 7), while in the other case both partners met at a conference and decided to collaborate directly thereafter (DDLSF 3).

In several cases, DDLSFs are invited by partners to form a partnership. This occurred in two partnerships with research institutes. In one case, the DDLSF was approached by a partner acquainted with the managers of the DDLSF through their previous job occupations (and thus ended up at the DDLSF through the professional network of these managers). In the other case, publications and patents led the employees of a research institute to the DDLSF. In one other partnership, a third organisation also engaged in the partnership approached the DDLSF for collaboration along with a research institute (DDLSF 1). This third organisation had already been a partner of the DDLSF in the past. This third organisation thus represented a relation from the firm's prior network of collaboration, through which the DDLSF became acquainted with the research institute.

With regard to partnerships with other firms the DDLSFs are found in four cases, two of which directly through the network of contacts of the partnering firm. In one other case, the partner found the DDLSF through its patents (DDLSF 5) In the remaining case a meeting at an event directly resulted in formation of the partnership (DDLSF 4).

Table 5.6 shows that more established firms do not depend on relatively coincidental meetings at events to find partners. These more established firms often already know their partners through their network of established contacts, or have a thorough overview of the sector or field of knowledge so that they can assess which organisations could be potential partners for a certain project. Some of the partnerships of unestablished firms depend heavily on both organisations meeting at an event. These partnerships were subsequently formed thereafter. So while both established and unestablished firms stated to attend events in order to increase both their knowledge of the field and their visibility for other organisations in that field, as was shown in Table 5.3, only relatively unestablished firms seem to depend on such coincidental contacts for establishing their most important partnerships. Established firms seem to know better who to partner with, whereas unestablished firms do not know with whom to partner as yet. Collectively, these findings suggest that search processes evolve from untargeted, open searches with relatively unknown options, to targeted searches with known options for partnering.

Selection among several potential partners
Looking more closely at partner selection it may be concluded that, especially for partnerships with research institutes, DDLSFs barely consider other potential partners in addition to the

partner that is eventually chosen. Searching DDLSFs only explicitly consider other partners when they find their partner through their network of existing contacts (directly or indirectly). Strikingly, we found that when internal knowledge was used to find a partner, no other organisations were taken into consideration.

In partnership formation processes in which a partner takes the initiative (6 partnerships), only in one instance did the DDLSF indicate to have considered other partners as well. This was the case (DDLSF 5) in which patented knowledge played a crucial role; this DDLSF had patented knowledge which was required by the partner for the development of a certain medicinal product. So on the one hand, this patented knowledge made the DDLSF visible to other organisations within its environment, and on the other hand it provided the DDLSF with a stronger negotiating position, enabling it to choose the partner offering the best financial returns.

Search and selection in jointly initiated partnerships

Table 5.6 shows that one project of a DDLSF with a research institute and two projects of DDLSFs with a firm were actually jointly initiated, in which the phase of searching for a partner was skipped. Two of these partnerships constitute repeated ties of the organisations involved (one partnership of a DDLSF with a research institute and one of a DDLSF with another firm). Consistent with the idea of 'repeated ties' is that formalisation occurs, which materialised in shared specific deliverables and results of the partnership. In other words, these partners share the performance risk of the project, as discerned by Das and Teng (1998).

In jointly initiated partnerships also considering other potential partners was not regarded as relevant by the DDLSFs involved since the ideas for establishing these partnerships derived from discussions with these potential partners, as was also indicated in other studies on partnership formation (Gulati, 1998).

5.4.5 A comparison of inducements, opportunities and search between different types DDLSFs

In this section, possible differences in the partnering behaviour of firms with and without patents are examined. As was done in the previous sections on the results of this study, we address possible differences in inducements, opportunities and finding partners/being found.

Table 5.7 provides data on the primary inducements of different types of DDLSFs for engaging in partnering with research institutes and firms. In all four partnerships of relatively unestablished firms without patents gaining access to technological knowledge and facilities is the most important inducement for partnering. As to other types of DDLSFs, the primary inducements for partnering with other firms are more varied; obtaining access to resources related to commercialisation and obtaining financial resources are also of importance here. Furthermore, unestablished firms without patents engage in collaboration to gain access to complementary technological knowledge and facilities while commercialisation seems to be of little relevance. Other firms also engage in partnering to obtain financial resources and resources related to commercialisation.

Table 5.8 shows that relatively unestablished firms without patents are not involved in the actual initiation of collaboration projects. These firms depend to a large extent on partnerships that were initiated by their partner and are also involved in jointly initiated partnerships. Relatively

Table 5.7 Primary inducements for partnering of different types of DDLSFs; RI = partnership with research institute; F = partnership with firm

Primary inducements	**Unest. firms without patents (2 firms, 4 projects)**		**Unest. firms with patents (4 firms, 7 projects)**		**More established firms without patents (1 firm, 2 projects)**		**More established firms with patents (2 firms, 3 projects)**		**Total**
	RI	**F**	**RI**	**F**	**RI**	**F**	**RI**	**F**	
Technology/ facilities	2/2	2/2	2/3	–	1/1	–	1/1	1/2	9
Commercialisation	–	–	–	2/4	–	1/1	–	–	3
Finance	–	–	–	2/4	–	–	–	1/2	3
Other	–	–	1/3	–	–	–	–	–	1
Total	2	2	3	4	1	1	1	2	16

Table 5.8 Initiation of partnerships by different types of DDLSFs; RI = partnership with research institute; F = partnership with firm; rep. tie = repeated partnership

	Unestablished firms without patents (2 firms, 4 projects)		**Unestablished firms with patents (4 firms, 7 projects)**		**More established firms without patents (1 firm, 2 projects)**		**More established firms with patents (2 firms, 2 projects)**		**Total**
	RI	**F**	**RI**	**F**	**RI**	**F**	**RI**	**F**	
Partnerships initiated by partner	2/4	1/4	1/7	2/7	–			1/3	7
Partnerships initiated by DBF	–	–	2/7	2/7			1/3	1/3	6
Jointly initiated partnerships	–	1/4 (rep.tie)	–	–	1/2	(rep. tie)1/2			3
Total no. of partnerships	4		7		2		3		16

unestablished DDLSFs with patents do initiate partnerships with research institutes as well as with firms. More established firms also show a relatively low dependence on partnerships initiated by the partner. The most important projects of the more established firm without patents are jointly developed partnerships. More established firms with patents form the majority of their most important partnerships with research institutes and firms on their own initiative. These results thus indicate a difference between firms with and without patents in the extent to which they initiate partnerships: firms with patents are more frequently initiators than firms with no patents. Further specification of Table 5.8 by including sources of finding partners or being found, fails to provide much additional insight. As can also be derived from Table 5.6, networks of the contacts of organisations constitute an important source of finding partners and being found, both directly and indirectly. Events are of less importance in comparison with such networks, and are only used by unestablished firms (with or without patents).

Table 5.9 Selection of partners by a specific type of DDLSF; RI = partnership with research institute; F = partnership with firm; jointly initiated partnerships are omitted from this table.

Others considered by DDLSF after initiation by the DDLSF?	**Unest. firms without patents (2 firms, 4 projects)**		**Unest. firms with patents (4 firms, 7 projects)**		**More established firms without patents (1 firm, 2 projects)**		**More established firms with patents (2 firms 3 projects)**		**Total**
	RI	**F**	**RI**	**F**	**RI**	**F**	**RI**	**F**	
Yes	–	–	1	1	–	–	–	1	3
No	–	–	1	1	–	–	1	–	3
Others considered by DDLSF after initiation by partner?									
Yes	–	–	–	1	–	–	–	–	1
No	2	1	1	1	–	–	–	1	6
Total	2	1	3	4	–	–	1	2	13

The results in Table 5.9 answer the question whether different types of firms have considered other partners in addition to the partner that was eventually chosen. In the table a distinction is made between partnerships initiated by the DDLSF and those initiated by the partner. With regard to partnerships initiated by the DDLSFs, in three out of six cases other partners were also taken into consideration. Firms that had not obtained patents also did not initiate any partnerships (the more established firm without patents collaborates in two jointly initiated projects). Only once did any of the DDLSFs consider other potential partners after initiation of the partnership by a partner. In this respect it is not usual to consider other partners when the initiative to establish the partnership has been taken by the partner. To be found and be invited seems to preclude partner comparison. The only case observed of a firm doing this is a DDLSF with a patent that was an explicit part of the partnership. Since there were other organisations that also had an interest in obtaining the intellectual property protected by this patent, the DDLSF was able to make a selection from offers. This case does, however, only represent one example of a case where patents clearly gave a firm a better negotiating position. Overall, it can be concluded that in half of the cases when a DDLSF initiated a partnership, multiple organisations were taken into consideration as partners. In our study, firms without patents have not taken the initiative to establish partnerships. In partnerships initiated by the partner, the DDLSF usually does not consider other potential partners, except for one case in which patents had improved the negotiating position of the DDLSF.

5.5 Discussion

The aim of this chapter is to provide an insight into resource-based inducements and opportunities of DDLSFs for partnering, as well as into the process of searching for partners. While many other studies have focused on motives for collaboration, such motives are often more general in stead of specific with regard to the partner that is chosen. In this study, we have attempted to provide insight into the motives for partnering with a certain partner, thereby linking the motives for partnering and searching for a partner. In this respect, we adopted a distinction made in literature between inducements and opportunities for partnering (Ahuja, 2000; Sakakibara, 2002). In retrospect, applying this distinction is considered relevant, as managers were able to indicate both. Diverse configurations of resource-based inducements and opportunities were found, some indicating complementarity within a single type of resource and others indicating complementarity across different types of resources. In other studies employing a firm-level perspective (Ahuja, 2000; Sakakibara, 2002), the possibility of inducements and opportunities for partnering of the focal firm being based on the same type of resource was not taken into account.

Subsequently, the extent to which an organisation is able to identify other organisations within its environment that are able to fulfil its inducements for partnering depends on the amount of information available to it on such potential partners. In this regard other studies stressed the role of existing networks of collaboration (Gulati, 1999; Ahuja, 2000). Such a network may directly and indirectly contribute to the identification of partners (Gulati, 1998). However, other types of relationships than those based on previous collaboration may also exist between two organisations (Gulati, 1998: p. 302). The exploratory nature of this study enabled us to include a broader range of types of previous relationships between partners by addressing the extent to which partners are found in networks of contacts. The social capital of a firm thus gives direction to the process of searching for partners. Attending events seems to be important in terms of accumulating social capital.

We found here that networks of previous contacts constitute an important source of finding partners and being found, both directly and indirectly. While we did find that 2 out of 16 R&D partnerships are repeated ties between organisations, and one in which the DDLSF met its partner through a previous partner, in most cases contacts were not previous partners. In eight cases, the DDLSF and its partner were related either in a different manner or had been introduced to one another by a different type of contact. Such different types of contacts include previous employers of managers and, for instance, members of DDLSF advisory boards. The effects of these other contacts would have remained unnoticed in a study focusing solely on the effects of previous networks of collaboration, and yet they might especially be of relevance in emerging sectors or technological fields. In such fields, networks of collaboration are only just emerging, and relationships that constitute these networks are highly volatile (see also Chapter 3 of this thesis). Furthermore, several managers of DDLSFs stated that obtaining access to the network of contacts of either their partner or themselves constituted an inducement, respectively an opportunity for partnering, from their own perspective. However, the perceived importance of gaining access to such networks was always less than that of gaining access to technological knowledge and/or facilities, which may be an indication of the technological specificity of networks of collaboration in such an industry.

This study has also provided some starting points for further research as it has indicated some possibly promising hypotheses on the relationship between patent acquisition and motives for partnering and the search for and selection of partners. First of all, firms that had acquired patents were more often the initiators of partnerships. This could be due to effects described in earlier literature that patents seem to induce commitment of resources to further development of the patented invention (Mazzoleni and Nelson, 1998). Another cause might be that the increased attractiveness of firms with patents improves their chances of finding other organisations that are willing to collaborate.

Moreover, we also found that firms with patents were generally more interested in collaboration in order to obtain either resources related to commercialisation or financial resources. Patent acquisition might thus influence the inducement of firms to engage in collaboration. Such 'commercialisation-inducing' effects of patents have also been discussed before (Mazzoleni and Nelson, 1998). Overall, patent acquisition thus seems to influence inducements for partnering as well as processes of partner search.

Judging from the data obtained in this study, similar effects may be relevant when differences between relatively unestablished and more established firms are examined. However, as this study only included one more established firm without patents, this remains relatively speculative. Data on the partnerships of this firm do seem to show increased possibilities of jointly initiated partnerships as opposed to depending solely on initiatives being taken by partners. Such effects of the extent of establishedness on the partnering behaviour of firms examined here may be related to effects incorporated in the liability of newness (and smallness) (Stinchcombe, 1965; Freeman et al., 1983). Among other things, these effects include a lack of social approval of new organisations and specific, ensuing consequences of this, such as their lack of stable relationships with other organisations (for instance suppliers) within their environment. This lack of social approval generally makes it difficult for new firms to find other organisations that are willing to collaborate, which can increase their dependence on initiatives taken by potential partners. However, as the aim of this study was to explore inducements, opportunities and search and selection, the findings presented in this chapter should be regarded as potential starting points for further research.

Other studies have also shown that more established firms have more partnerships (see for instance Chapter 4 of this thesis). From the exploratory study conducted here it was derived that such an increase in the number of partnerships is mainly attributable to the increase in the extent to which a firm is able to successfully initiate partnerships, thereby primarily fulfilling its own inducements for partnering. More established firms and firms with patents are more able to find partners willing to collaborate, in addition to accepting project proposals of potential partners. While relatively unestablished firms might also be considered highly induced to engage in partnering as these firms have not had the time to accumulate resources in-house as yet, these unestablished firms are more dependent on proposals for partnering offered to them by induced partners.

As this study was of an exploratory nature it mainly provides interesting insights for further research to examine partnering in an emerging technological field, instead of drawing definite conclusions on partnering. One of the limitations of this research concerns its sole focus on partnerships that have been established, thereby neglecting project proposals that have been turned down by one of the potential partners. Also addressing such proposals could provide additional insights into the extent to which organisations are actually selective when possibilities for collaboration are offered to them by potential partners. Moreover, there could be differences in the extent to which invitations for partnering are accepted, for instance related to the type of resource requested by the potential partner. Firms could be less likely to accept a proposal to share its critical resources, determining its strategic competitive advantage, with a partner. Also, as all the processes of search and selection based on inducements and opportunities studied here have led to the formation of a partnership, the managers of the DDLSFs that were interviewed might to some extent have rationalised this process in retrospect. However, given that we gathered the data by conducting interviews, we were able to follow up with inquiries into, for instance, how the two partners met.

Finally, when looking at the inducements and opportunities of the DDLSFs for partnering, we only interviewed the managers of these DDLSFs, and not their partners. The result was that we only gained insight into the opportunities of the DDLSF *as perceived* by the DDLSF and not the opportunities as perceived by the partner. Keeping in mind the definition of 'opportunities for partnering with a specific partner', namely that they represent the extent to which an organisation is able to fulfil another's resource needs, it might be more sound to base information about these opportunities on the opinions of the partner. Moreover, it might be interesting to examine the extent to which the perception of ego is in agreement with the perception of alter. Also, interviewing the partners of DDLSFs would have provided more insights into the processes of search and selection initiated by them.

5.6 Conclusion

The central research question of this chapter is: "*Which inducements and opportunities guide interorganisational R&D partnering of Dutch dedicated life sciences firms and in what ways do these firms search for partners?*" To answer these questions this exploratory study made use of data obtained from interviews held with managers of nine DDLSFs. In total, the inducements, opportunities and search processes of 16 R&D partnerships were discussed.

Primary inducements for partnering of the DDLSFs were related to gaining access to technological resources, especially in the case of partnerships with research institutes. These research institutes especially have complementary knowledge in the fields of biology and pharmacology. DDLSFs perceive their technological as well as their commercial resources as being primary opportunities for partnering with these research institutes. DDLSFs indicate to engage in partnering with other firms to obtain access to technological as well as commercial resources, while they perceive their opportunities as deriving mainly from their technological resources. Overall, in most cases, the primary motive of the organisation (DDLSF or its partner) that initiates the partnership is to access complementary technological resources.

Networks of the firm's contacts constitute an important source of finding partners and being found. In three cases, such contacts represented previous partners. However, in eight cases those contacts represented other types of contacts. These findings indicate the relevance of examining the influence of different types of networks of organisations, connected by types of relationships other than just previous partnerships.

In addition to these findings, the study has also provided some directions for further research, especially with regard to differences in partnering behaviour between firms with and without patents. First of all, firms with patents were more frequently found to initiate partnerships, i.e. to take the initiative in establishing a partnership. Furthermore, firms that initiate partnerships are more likely to take multiple partners into consideration before choosing a specific partner. Secondly, obtaining access to resources related to commercialisation and financial resources were more frequently mentioned as inducements for partnering by firms with patents than by firms without patents, indicating some kind of commercialisation-inducing effect of patent acquisition (Mazzoleni and Nelson, 1998). Also, as DDLSFs become more established there seems to be a shift in the extent to which they are able to form partnerships at their own initiative: more established firms seem to be more successful in this respect. While unestablished firms accept invitations to partner, more established firms more often seem to know what they need and act accordingly. These more established firms do not depend on relatively coincidental meetings with potential partners at events, but already know their partners through their network of contacts, or have a thorough overview of relevant knowledge fields and know whom to partner with. In the latter case, more established firms are not inclined to consider multiple potential partners. This is also the case for most partnerships that were initiated by a partner. In these cases DDLSFs seem to display satisficing behaviour (Simon, 1957).

While these findings were obtained by studying 16 partnerships of DDLSFs, further research may provide insight into the extent to which these findings are also applicable to partnerships of a larger sample of DDLSFs.

6 Discussion and conclusion

The aim of this thesis is to address the factors that contribute to the ability of technology-based firms active in an emerging technological field to collaborate with other organisations. Uncertainties deriving from the emerging nature of the field in which these firms are active induce them to engage in collaboration. New technological developments succeed one another rapidly, generating uncertainty about which technological opportunities to seize, and lead to a distribution of knowledge and competences across firms. Subsequently, as these firms are founded on the basis of promising inventions within this emerging technological field, many of these firms are young and consist of only a few employees, making them susceptible to the liability of newness and smallness, and increasing their chance of failure (Freeman et al., 1983). The lack of external legitimacy of a firm has been referred to as the general cause for these liabilities, indicating the importance to improve this legitimacy (Singh et al., 1986). Engaging in partnering can help in this respect (Stuart et al., 1999; Baum et al., 2000). Jointly, the characteristics of the technological field in which these firms are active, as well as organisational characteristics, make engaging in partnering of importance. However, given that they increase the level of uncertainty with regard to the firm's future performance, these characteristics may also be conceived as reducing the likelihood of a firm to find other organisations interested in collaboration. The aim of this thesis is therefore to unravel the factors that contribute to partnering by Dutch dedicated life sciences firms (DDLSFs). The central research questions are: *How can developments in the macro-level context of partnering by DDLSFs, consisting of technology dynamics and network dynamics, be characterised in the period 2000-2004?* And on the micro-level: *What factors related to resource-based inducements and opportunities as well as to structural sociological opportunities contribute to explaining interorganisational partnering by DDLSFs on the micro-level?* In order to answer these questions, this chapter will integrate the findings of the empirical chapters 2 to 5, thereby relating the findings on partnering on the micro-level to findings on technology dynamics and network dynamics. These two latter aspects represent part of the context in which partnering occurs. The distribution of technological knowledge across organisations may direct the formation of partnerships between these organisations, indicating the relevance of studying technology dynamics. Networks of partnerships may exert endogenous effects on the formation of new partnerships. Also, a network of partnerships is an accumulation of individual partnerships between organisations and therefore also an expression of the partnering behaviour of organisations on the population-level. In this respect, the network represents an aspect of the partnering behaviour of organisations that could be further explained by using findings on the level of the firm and partnership, also obtained here.

The different issues presented in Figure 1.2 will be addressed successively in the following sections. We will start by discussing the findings on the network of partnerships and technology dynamics, and subsequently focus our discussion on inducements and opportunities for partnering on the level of the firm. In Section 6.3 we specify structural sociological influences on the process of searching for partners.

6.1 Network and technology dynamics as contexts of partnering: volatility and structure

The analysis of the dynamics of partnering by DDLSFs on the macro-level (Chapter 3) showed that, while research institutes are and remain the most central nodes in the network, the volatility of the partnerships that compile the network is high. These findings are in accordance with other findings on the structure of collaboration networks in the life sciences (Powell et al., 2005). The influence of technological developments on these network dynamics was proposed in studies on network dynamics conducted by Gay and Dousset (2005) and Powell et al. (2005). Gay and Dousset find that the primary hubs in the network are firms holding the most important patents within the biotechnology subfield of antibody development, while Powell et al. (2005) indicate that the continuing introduction of new organisations into the network represents a sign for the network's 'accessibility to novelty' (p. 1198). In this thesis, we are able to relate the findings on network development to findings on technology dynamics generated by the same focal organisations. The findings on technology dynamics show that there is variety in the technological foci of newly founded firms and that this variety increased slightly over time. Individually, these firms are highly specialised (Chapter 2). In one of the technological fields, namely 'proteins and other molecules' relatively many firms are active. This field attracts both specialists and firms combining technological fields.

The high degree of specialisation of the individual firms limits the number of partnerships formed between DDLSFs (Chapter 3). This was also suggested by Gilsing and Nooteboom (2006) who studied the Dutch pharmaceutical biotechnology sector. Dutch research institutes and especially Dutch universities, being large, multidisciplinary organisations, are important partners in collaborative R&D projects of DDLSFs. As universities consist of numerous departments, each with their own specific knowledge, these diverse departments represent attractive partners to DDLSFs with diverse technological foci. In this respect, these research institutes assume a role similar to *technology generalists* as defined by Orsenigo et al. (2001), as they are able to provide DDLSFs with fundamental knowledge on a variety of specific applications of their knowledge, as well as access to facilities for conducting R&D. Research institutes are found here to introduce structure into the network, as they were able to fill central positions in the network of partnerships in 2002 and, at least as a group of organisations, maintained this position from 2002 to 2004.

As was shown on the partnership-level, DDLSFs primarily engage in partnering with research institutes in order to gain access to their fundamental knowledge in the fields of biology, pharmacology and medical science in general (Chapter 5). Universities with a medical faculty are therefore most central in the network (Chapter 3). The different research groups of such a faculty, focusing for instance on different areas of human disease, have knowledge that is highly relevant for DDLSFs working on the development of all kinds of life sciences-related inventions. In addition to this knowledge, research institutes also provide access to facilities for research and development, including patient populations (Chapter 5). DDLSFs and other firms mostly do not occupy such central positions in the network as research institutes do.

6.2 Resource-based inducements and opportunities for partnering

With regard to the firm-level, explanations for partnering are also provided in this thesis by addressing inducements and opportunities of DDLSFs for engaging in partnering (Chapter 4 and (partly) Chapter 5), as was summarised in Figure 1.1 presented in the introductory chapter. This distinction between resource-related inducements and opportunities for partnering represents a refinement of the Resource-Based View in explaining interorganisational partnering.

The primary inducement for partnering was found to be the lack of sufficient technological knowledge, reflected in the number of patents of the firm. In this respect, this firm-level analysis indicates that partnerships are, at least to a certain extent, technology-specific, as they seem to be driven by a search for complementary technology. Primary opportunities for partnering were the prior acquisition of venture capital, prior business development and current business development, reflected in the change in turnover compared to the previous year. Indirectly, patenting has a positive, possibly reputation-related effect on the partnering rate as it positively influences venture capital acquisition, which in turn positively influences the partnering rate of the firm. These findings show that on the one hand engaging in partnering reflects the need for complementary (technological) knowledge. On the other hand, it is indicative that the organisation's financial viability, which includes business development as well as the external acquisition of capital, is important for generating partnering opportunities.

A firm-level analysis of the partnering rate that was also conducted in other studies (Ahuja, 2000; Sakakibara, 2002) provides insight into variables that influence the extent to which firms are in need of and able to establish partnerships with other organisations. Such an analysis however does not account for the fact that at least two organisations are active in a single partnership. Each organisation involved has its own specific inducements and opportunities for partnering. In this respect, from a resource-based perspective partnerships are used by organisations to gain access to *each other's* resources. Especially with regard to the technological resources of organisations which are highly specific (Chapter 2) it is quite possible that both organisations are active in the partnerships in order to make use of specific technological knowledge held by their partner. To provide further insight into both the perspectives of ego and alter we specified our analysis of partnering to the level of the individual partnership, focusing specifically on R&D partnerships (Chapter 5). In Chapter 3 of this thesis, R&D partnerships were found to constitute the large majority of all partnerships, a finding which in itself is another signal of the importance of technology in partnering.

In most of the partnerships studied in detail in Chapter 5 (ten out of sixteen), gaining access to the partner's technological resources was among the three most important inducements of ego as well as alter, and in four cases the DDLSF and the partner involved were both primarily induced to engage in partnering to gain access to these technological resources. Moreover, in most cases it was the primary inducement of the organisation that initiated the partnership, which can be either the DDLSF or its partner. Inducements and opportunities related to knowledge of commercialising technology and finance were also of importance. In partnerships with research institutes these types of resources constitute opportunities for partnering of DDLSFs, while in partnerships with other firms these types of resources are inducements of DDLSFs. This is in line with the relative position of research institutes compared to DDLSFs within the value chain.

6.3 Structural sociological influences: finding partners

In Chapter 3 of this thesis, the network of partnerships of DDLSFs was described and analysed, as also was its development from 2002 to 2004. A high degree of volatility became apparent from the analysis of its development. This volatility was expressed with regard to the hubs in the network, as well as the individual relationships that compile the network. The hubs in the network remained primarily research institutes, but the connectedness of individual research institutes varied over time. The volatility of individual partnerships might be attributable to the fact that they are meant to be short-term beforehand, or they are discontinued prematurely (or at least the relative importance of different partnerships of a DDLSF varies over time). Also, more than half of the new partnerships in 2004 were formed with partner organisations that were new to the network compared to the 2002 network. This susceptibility to novelty was also found in the study on networks in the life sciences conducted by Powell et al. (2005). Developments in collaboration networks are the result of decisions regarding partnering made by individual organisations residing on the micro-level (Kogut, 2000). More specifically, they are driven by decision-making with regard to which projects should be launched and the specific organisations that are preferred and willing to collaborate in these projects.

The structure of the network, as determined here by the degree distribution of its nodes, was shown to be almost random in 2002 and became only slightly more structured between 2002 and 2004. Combined with the high volatility of individual relationships, this finding indicates that the level of stability of the network of collaborative relations is low, possibly limiting the strength of effects endogenous to this network on its subsequent development (see also Gulati and Gargiulo, 1999). This implies that the directing effects of this network of collaboration on the search for a new partner may be limited. While other studies have made use of indicators of social capital reflecting the prior position of the firm within networks of partnerships in order to predict subsequent partnership formation (Gulati, 1995, 1999; Ahuja, 2000) such indicators may be of less relevance here to address the social capital of the firm. This could partly be attributable to the relative establishedness of the organisational fields in which these studies were conducted (namely mostly large, multinational firms) compared to the emerging field of dedicated life sciences studied here, with its relatively young and small firms.

In the analysis of the number of partnerships of the firm (Chapter 4), we made use of another indicator of the social capital of a firm, and especially of a start-up, namely the number of managers (Eisenhardt and Bird Schoonhoven, 1996). In this firm-level analysis, no direct effects of the number of managers of the firm on its partnering rate could be discerned. The number of managers apparently only has an indirect influence on partnering because it has a positive influence on the acquisition of venture capital. In this respect, the social capital of the start-ups examined, as embedded in their management team, does influence the specific external contacts of the firm with organisations in its environment, as it contributes directly to the chances of acquiring capital from external sources (Baum and Silverman, 2004), but only has an indirect positive influence on partnering.

On the level of the partnership, networks of the contacts of managers were found to be of importance to the specific choice of a partner. While a few partnerships were established on the basis of information provided by previous collaboration partners, most partnerships were formed using other sources of information, which mostly were other types of contacts of the managers of the firm. Also, some of the partnerships studied were formed after relatively coincidental meetings of managers at conferences for instance. Attending such events has also been mentioned in general as contributing to the organisation's social capital and can therefore reveal interesting possibilities for partnering in the future. Apparently, in this young field of Dutch dedicated life sciences firms, other networks comprised of other types of contacts are more important than merely networks of collaboration. Again, this may be related to the emerging nature of the field studied here, and is an indication of the volatility of the processes of searching for partners.

Overall, there is a wide variety of search processes; either the DDLSF or its partner can be the initiator of the partnership and both organisations have specific inducements and opportunities for partnering. The way in which the initiator searches for partners was shown to be volatile in itself. Subsequently, the extent to which both the DDLSF and its partner are inclined to consider multiple partners for carrying out the project may also differ. Two characteristics of the DDLSFs involved were found to possibly structure this variety, namely the relative establishedness of the DDLSF as well as whether or not it had obtained a patent.

While the resource-based variables used in the firm-level analysis of the partnering rate (Chapter 4) are stocks of resources, the firm-level attributes applied in the partnership-level exploration (Chapter 5) are dichotomous *thresholds*: whether or not DDLSFs had at least one patent, and whether according to predefined criteria they could be considered relatively established or not. In this respect, patents are regarded as a type of technological resource, with a potentially important influence on the process of finding partners. We attempted to relate these two thresholds to processes of finding partners, in order to derive directions for further research.

More established firms were found to initiate partnership formation, either alone or jointly with their partners (Chapter 5). These firms seem to know better what they need for the further development of their invention(s), possibly due to the accumulation of knowledge and experience obtained from earlier projects. Overall, more established firms seem to employ a mixture of projects initiated by themselves and joint projects undertaken after the invitation of a partner, which is in accordance with findings of Arora and Gambardella (1990). On the level of the firm, this leads to an increase in the partnering rate of these DDLSFs (Chapter 4). The potential influence of patent acquisition on partnering was related to its commercialisation-inducing effect, as described by Mazzoleni and Nelson (1998). The exploratory analyses of Chapter 5 indicated that firms that had acquired patents were more interested in gaining access to commercialisation-related knowledge and seemed more likely to succeed in establishing partnerships on their own initiative. The potentially structuring influences of patent acquisition and establishedness are subjects for further research.

The different processes of searching for a partner operating on the micro-level that lead to partnership formation, compile a network of partnerships in which research institutes are the hubs. A reason for the central position of research institutes in the network, deriving from processes of partners search, may be related to the fact that many of the DDLSFs studied here are university spin-offs (BioPartner, 2005), which is in agreement with the science-based character of the technological field. The managers of these firms therefore already have contacts at these universities. These contacts of the managers of firms were found to be of influence on the actual choice of a partner (Chapter 5). This then provides an explanation for the central position that research institutes occupy in the network of partnerships of DDLSFs in addition to the fact that they can also provide a DDLSF with access to knowledge and facilities.

A finding that requires further clarification is the different roles of patent acquisition derived in the different chapters. In the second chapter of this thesis, a conceptualisation of technology dynamics was developed and applied to the case of Dutch dedicated life sciences firms. The emerging nature of the field studied, as well as the organisations active in this field, precluded us from making use of patent statistics. As an alternative, we focused on technology portfolios at the time of founding based on information about technologies in use obtained from the firms' websites. This might seem to contradict the findings on explaining the partnering rates of DDLSFs and the link made in Chapter 5 between DDLSFs with and without patents and the way these firms establish partnerships. Whereas we considered patents to be a too narrow starting point for unravelling the *content* of technology portfolios of the relatively young firms in our study (to clarify: one third of the firms included in our sample has no patents as yet), this does not imply that patents are not a relevant reflection of the firms' *stock* of technological resources.

6.4 Implications and suggestions for further research

To summarise, in addressing partnering this thesis has focused on technology dynamics, network dynamics, firm resources from which inducements and opportunities for partnering were derived, and the processes involved in finding partners. Relating the findings on macro-level developments of technology and networks within the sector to partnering residing at the micro-level constitutes the main contribution of this thesis. In this respect, several implications can be derived from this research.

On the level of the population of firms, it was shown that the technological diversity of subsequent populations of newly founded firms increased slightly over time (Chapter 2). While predictions of technological change within an emerging field must be based primarily on expectations, this increase rather than decrease in technological diversity may further increase the uncertainty about the future direction of technological change. This makes it increasingly difficult for all types of actors, including policy makers, established firms and venture capitalists to decide which technological opportunities to support or develop further.

Furthermore, universities were found to be the hubs in the network comprised of partnerships of DDLSFs. This finding is in accordance with the science-based character of the technological field, as well as with findings on inducements for partnering, which are primarily related to gaining access to technological knowledge. The centrality of universities may also be indicative of the emerging nature of the field of life sciences and the prematurity of the firms studied here. However, as has been shown in Chapter 4 of this thesis, business development, both prior and current, and thus exploitation and growth are important for partnering. The increasing importance of business development has also been stressed in literature on business models (Willemstein et al., 2006; Ernst & Young, 2004). Gilsing and Nooteboom (2006) identify that relationships with universities dominate in networks aimed at exploration rather than exploitation. Engaging in collaboration primarily with universities may not contribute to exploitation as much as collaboration with firms.

On the micro-level, the primary inducement of DDLSFs for partnering is to gain access to the technological knowledge of their partners (Chapters 4 and 5). The relatively specialised technology portfolios of DDLSFs (Chapter 2) may be expected to motivate this search for complementary technological knowledge. However, some aspects were found to interfere with this seemingly rational structuring of partnering based on the complementarity of technological knowledge. On the level of the firm, business development, both prior and current, was found to positively influence the partnering rate of DDLSFs. This implies that relatively more positive prior and current business development provide a DDLSF with opportunities for partnering. Such a positive effect on partnering was also exerted by the acquisition of venture capital.

On the level of the partnership itself, the variety in search processes was found to be large. In these processes, previous partners and information obtained from previous partners was relevant in some cases, but in most cases information on promising partners was obtained from other types of contacts introducing new organisations into the network of partnerships (Chapter 3). In only a few cases, multiple potential partners were considered, from which a selection was made. In the case of more established firms, this omission to make a selection from multiple potential partners seems to be attributable to the idea that they seem to know what they require and are able to determine who to partner with in order to obtain access to it. Where partnerships initiated by the partner are concerned, satisficing behaviour seems to be exhibited by the DDLSFs involved (Simon, 1957) (Chapter 5). This finding indicates that for many DDLSFs partnering can be characterised by trial and error learning, rather than adhering to a strategy determined beforehand. This might significantly impact the subsequent chance of success of the partnerships established. The high volatility of partnerships found in Chapter 3 of this thesis may be related to this: firms either decide to partner only for a limited period, or these partnerships are often discontinued prematurely.

The general tendency to consider engaging in partnering as being good for organisations is based on the idea that partnerships can be used to reduce the *performance risk* of projects, which refers to the risk of not achieving the aims of the project (Das and Teng, 1998). If partnering is based on trial and error, the extent to which the performance risk of projects is reduced may be limited. Namely, in order for this performance risk to be reduced by partnering, the inducements and opportunities of the organisations involved in the partnership need to be sufficiently complementary. Achieving a high level of complementarity may be expected to be influenced by the extent to which each of the organisations 'knows' that its partner organisation can provide the resources required. This indicates the importance of search and selection in partnership formation, and is in contrast to the satisficing behaviour observed in some of the processes of finding partners examined in this study. If the complementarity of inducements and opportunities of partnering organisations is low, then the project's performance risk is likely to be high (as the partners are unable to provide each other with access to the required resources). Along the same line of thought, there might also be a maximum amount of overlap of technological knowledge, above which the performance risk also increases. This is related to findings in earlier literature on the extent of technological overlap of partners (Mowery et al., 1998), or, the other way around, on their cognitive distance (Nooteboom, 2000; Gilsing and Nooteboom, 2006; Nooteboom et al., 2007).

While carrying out projects in the form of collaboration with another organisation aims to reduce the performance risk of those projects, this introduces *relational risk* (Das and Teng, 1998), which constitutes a potential drawback to engaging in partnering. Aspects related to opportunistic behaviour are of importance in this respect. When satisficing behaviour is displayed by an organisation that decides to partner with another organisation with which it is already familiar, the reduction of the relational risk caused by this familiarity might weigh up to a possible increase in the performance risk of the project caused by satisficing behaviour. Further research could provide insight into the relation between the complementarity of inducements and opportunities for partnering of ego and alter and the process of partner search preceding the formation of the partnership on the one hand, and the subsequent performance of the partnership on the other hand. On the level of the firm, relational and performance risk may together determine an optimal number of partnerships a specific firm should engage in. Further research could provide insight into the possible threshold of the number of partnerships after which the increase of the relational risk starts to exceed the reduction of the performance risk.

For conducting further research, explicitly addressing the position of all partners active in a partnership is important, otherwise the assessment of the actual complementarity of inducements and opportunities for partnering across partners engaged in a partnership would remain speculative. Moreover, with regard to the findings on the networks of partnerships of DDLSFs in 2002 and 2004, it can be concluded that several so-called alters in these networks of partnerships were highly influential in the further development of the network over time, namely the research institutes that occupy central positions in the network. This makes addressing the strategy of these organisations in partnering with DDLSFs important.

Finally, while the partnership-level analysis conducted in Chapter 5 focused solely on search processes leading to the formation of R&D partnerships, this study does not provide insight into the extent to which organisations are inclined to accept or reject certain invitations for partnering. Future research should address this issue as this contributes to the study of selection among potential partners and partnerships. This would coincide with the strategies of organisations for decreasing both the performance and relational risk, as discussed above.

6.5 Concluding remarks

Over the past decade, innovation policies in the Netherlands have been aimed at stimulating developments toward a knowledge-based economy. In this respect, improving the innovative capabilities residing within the Dutch economy is thought to be crucial as they were found to lag behind other European countries (Ministry of Economic Affairs, 2003). In improving these capabilities, stimulating developments in the area of biotechnology and the life sciences have been signalled as important. Due to the potentially pervasive character of this set of enabling technologies, impacting pharmaceuticals, chemicals, agriculture and food, innovation in the field of these technologies is considered to contribute to sustainable economic development (Ministry of Economic Affairs, 2004). To successfully make use of the opportunities provided by such a technological field, achieving both 'focus and mass' was considered to be of importance (Ministry of Economic Affairs, 2004; p. 3).

Government initiatives, the most visible of which was the BioPartner programme, have so far mainly been aimed at stimulating the founding of new dedicated life sciences firms. Targets regarding the number of new firms being founded have been achieved, and it seems that the business culture of Dutch research institutes has improved (Dongen et al., 2005). Overall, the status quo at the end of 2004 was life sciences as a technological field in which a growing number of young, dedicated firms was working. In order for these firms to contribute to innovation in this technological field in the Netherlands, it is crucial that they survive and grow, contributing to the desired development of continued 'mass' of research and commercialisation efforts within this field.

Several findings of this study might be of relevance in this respect. First of all, DDLSFs were shown to be highly specialised with respect to their technological focus. Also, since 2000, the technological diversity of newly founded firms overall seems to grow slightly rather than decrease. Secondly, these firms were shown here to focus on R&D collaboration, the most important partners being Dutch research institutes and foreign firms and to a lesser extent other Dutch firms (non-DDLSFs). While such characteristics may be indicative of the early development stage of the DDLSFs, these characteristics may also derive from the science-based character of the technological field, and might therefore be persistent, which would imply that Dutch research institutes remain to be the most central organisations within the collaboration network, unless they themselves change their strategy for collaboration with industry organisations. On the other hand, the findings of Chapter 3 of this thesis show a relative increase in the importance of foreign research institutes within the network of partnerships in 2004 compared to 2002. Moreover, if a so-called 'seamless integration' (Sager, 2001) of biotechnology-related knowledge will occur into existing application sectors especially firms focusing on human health-related applications, and subsequently those that are further along their product development trajectories, may require further internationalisation of the network of partnerships, as a pharmaceutical industry has hardly developed in the Netherlands.

Since the discontinuation of the BioPartner programme at the end of 2004, initiatives aimed at stimulating innovation in the life sciences have been merged into the more general TechnoPartner programme, aimed specifically at stimulating entrepreneurship in technology-based sectors, and also into the different so-called 'key areas' defined by the Dutch Innovation Platform. These key areas include 'flower and food', 'high tech systems and materials' and 'chemicals'. The fact that a pharmaceutical industry has hardly developed in the Netherlands is likely to be the reason for the omission of 'human health' or 'pharmaceuticals' from the list of key areas for innovation policy in the Netherlands, as compiled by the Innovation Platform. While defining key areas may contribute to the integration of individual life sciences firms into their application sector as referred to by Sager (2001), life sciences firms focusing on applications in the different technological fields related to human health might be overlooked, or at least perceive to be. The establishment of the so-called 'Top Institute Pharma' in July 2006 may be perceived to fill this policy gap to some extent.

Notes

1 Other studies have used the notion of technological convergence at the level of integrating industries or technological fields themselves, based on co-occurrence of patent categories (Duysters & Hagedoorn, 1998; Gambardella & Torrisi, 1998). Using the co-occurrence of patent categories as a measure of technological convergence implies that firms and other organisations actively and directly contribute to this process of technological convergence (Harianto & Pennings, 1994). We propose here, however, that these studies are mainly aimed at unravelling the convergence of technologies and their complementarity across industries; they unravel technological convergence *by* firms and other organisations. We focus on the technological convergence *of a population* of firms.

2 Note that the shares of the different technological fields do not add up to one in each year; after addition they exceed one due to the fact that one firm could be attributed to multiple technological fields.

3 As the number of values for the number of fields and the SD of the shares of these fields is limited to five, due to our focus on developments from 2000 to 2004, we have not been able to determine the statistical significance of the increase, respectively the decrease in these values over time.

4 When developments in the number of main fields covered by firms are considered, the majority of newly founded firms works in one of the specified main fields. Overall, the shares of firms combining more than two main fields are very low, resulting in steeper downward sloping lines for each year than the lines shown in Figure 2.7.

5 Using the explanation given earlier in this section, these 8 firms can be identified by counting the number of continuous black lines, each representing one firm combining knowledge of two main fields, and adding to this number the firms represented by differently styled lines. In this case the calculation leads to 6 + 2 = 8.

6 This implies a survival rate of 54.0% per year resulting in an average life expectancy of 2.17 years for collaborative relations of DDLSFs.

7 In this case, the negative power degree may increase but remains below the value 3 associated with a scale-free network (Barabási and Albert, 1999).

8 In 2002, the power degree of the network was -1.170, with a skewness of the distribution of indegrees of 1.35 and a kurtosis of 0.71. These values for skewness and kurtosis are nearly admissible deviations from their theoretical values of zero for assuming a normal distribution of the indegrees of nodes in 2002 (Boomsma, 1983; Faber, 1988).

9 It is important to note that venture capital acquisition is defined here as a one-way flow of financing and is therefore not considered to be a partnership in itself.

10 This distribution of 39 responding young DDLSFs does not significantly differ statistically from the distribution of the 74 out of 81 young DDLSFs that answered the survey questions on having or not having acquired a patent and venture capital ($p>0.10$); 12 none of either, 6 only venture capital, 18 only at least one patent, and 38 at least one patent and venture capital. Consequently, the 39 responding young DDLSFs are representative for the population of young DDLSFs in 2002.

11 When added to this final model, 'firm age' still had no significant effect on any of the other variables. It is therefore not included again. Exclusion of this variable and other insignificant effects somewhat changes the R^2-values and values of the coefficients, making them slightly different in Figure 4.2 compared to Table 4.3.

12 The indirect effect of a variable on another variable is calculated by multiplying the coefficients that are part of a sequence of effects operating on the partnering rate and adding these multiplications. For instance, the indirect effect of the size of the management team on partnering is calculated as follows: size of the management team (i) = 0.43*0.84=0.36.

13 The central notions of the resource dependence perspective concerning the division of power among partners in relationships and the extent to which engaging in these relationships enables them to reduce environmental uncertainty (Pfeffer and Salancik, 1978; Lewin et al., 2004) were not explicitly addressed in this thesis.

14 We have already attempted to re-test the model obtained here on a similar sample of firms (young DDLSFs) using data on the year 2004. In this 2004 dataset we were unable to confirm the findings presented in this paper. One reason for this could be the reduced reliability of the data on venture capital acquisition in 2004. To measure this in 2004 we had to combine the data from the 2002, 2003 and 2004 questionnaires which resulted in a high number of missing values on this variable. We aim to address this issue in further research and reassess the explanatory value of the model in 2004.

15 The majority of the managers interviewed were CEOs of the DDLSFs.

16 Only the (three) most important inducements are included in this table.

Appendix belonging to Chapter 2: Data used to compile Figures 2.8 to 2.12

	$TF1_{a-h}$	$TF2_{a-e}$	$TF3_{a-e}$	TF4	TF5	$TF6_{a-c}$	TF7	TF8	TF9	TF10	TF11
$TF1_{a-h}$	2000:1 2001:2 2002:2 2003:1 2004:2	2002:1	2002:1			2000:1				2000:1	
$TF2_{a-e}$		2000:5 2001:4 2002:1 2003:4 2004:1	2000:1			2001:2 2002:1 2003:1 2004:1			2000:1	2000:1 2004:1	2002:1 2003:2
$TF3_{a-e}$			2001:1 2002:1						2001:1	2000:1	
TF4				2000:2 2003:1 2004:1							
TF5											
$TF6_{a-c}$						2000:4 2001:1 2002:3 2004:4			2002:1		
TF7											
TF8											
TF9									2000:1 2003:1 2004:2		2004:2
TF10										2001:2 2004:2	
TF11											2003:1

6995

Figure A1 The opportunity matrix of firms combining 2 main fields or less (N=71). In this figure, a year of founding is given, followed by the number of firms founded in that year, in that specific field or a combination of two fields. For instance, the '2002:1' stated in the first row and third column means that in 2002 one firm was founded working on a combination of subfields of main fields 1 and 3.

Table A1 Technological fields of firms combining 3 or more main fields (N=11)

Firm	Field 1	Field 2	Field 3	Field 4	Field 5	Founding
Firm 1	2civ anti body	5c dna transfer	10 bioassays			2000
Firm 2	2c prot engineering	3a cell line	6cv 3d structure	11 drug delivery		2000
Firm 3	1e arrays	2ciii fusion	10 bioassays			2001
Firm 4	1b dna seq synth	1c genomics	2d proteomics	3d vaccine	10 bioassays	2001
Firm 5	2a prot seq/ synth	2cii enzyme	6civ chiral	11 drug delivery		2002
Firm 6	1a probes/ engineering	2ci site directed	2ciii fusion prot	10bioassays		2003
Firm 7	2d proteomics	3d vaccine	6cii high throu			2003
Firm 8	1b dna seq synth	2civ anti body	3d vaccine			2003
Firm 9	2civ anti body	3d vaccine	6cii high throu	6cv 3d structure		2003
Firm 10	1a probes/ engineering	2c prot engineering	5c dna transfer			2004
Firm 11	2 proteins general	7 nanobiotech	11 drug delivery			2004

References

Acharya, R., 1999. The emergence and growth of biotechnology: Experiences in industrialised and developing countries. Cheltenham: Edward Elgar.

Ahuja, G., 2000. The duality of collaboration: Inducements and opportunities in the formation of interfirm linkages. Strategic Management Journal, 21(3): 317-343.

Arend, R. J., Amit, R., 2005. Selection in strategic alliance activity: Effects on firm performance in the computing industry. European Management Journal, 23(4): 361-381.

Arino, A., De la Torre, J., 1998. Learning from failure: Towards an evolutionary model of collaborative ventures. Organization Science, 9(3): 306-325.

Arora, A., Gambardella, A., 1990. Complementarity and external linkages: The strategies of the large firms in biotechnology. The Journal of Industrial Economics, 38(4): 361-379.

Arora, A., Gambardella, A., 1994. Evaluating technological information and utilizing it: Scientific knowledge, technological capability, and external linkages in biotechnology. Journal of Economic Behavior and Organization, 24(1): 91-114.

Ayres, R. U., 1994. Toward a non-linear dynamics of technological progress. Journal of Economic Behavior and Organization 24(1): 35-69.

Barabási, A. L., Albert, R., 1999. Emergence of scaling in random networks. Science, 286(5439): 509-512.

Barnett, W. P., 1990. The organizational ecology of a technological system. Administrative Science Quarterly, 35(1): 31-60.

Bartholomew, S., 1997. National systems of biotechnology innovation: Complex interdependence in the global system. Journal of International Business Studies, 28(2): 241-266.

Baum, J. A. C., Calabrese, T., Silverman, B. S., 2000. Don't go it alone: Alliance network composition and startups' performance in Canadian biotechnology. Strategic Management Journal, 21(3): 267-294.

Baum, J. A. C., Rao, H., 2004. Evolutionary dynamics of organizational populations and communities, in: M. S. Poole and A. H. Van de Ven (Eds.), Handbook of organizational change and innovation. New York: Oxford University Press.

Baum, J. A. C., Silverman, B. S., 2004. Picking winners or building them? Alliance, intellectual, and human capital as selection criteria in venture financing and performance of biotechnology start-ups. Journal of Small Business Venturing, 19(3): 411-436.

Bayona, C., Garcia-Marco, T., Huerta, E., 2001. Firm's motivations for cooperative R&D: An empirical analysis of Spanish firms. Research Policy, 30(8): 1289-1307.

Belderbos, R., Carree, M., Lokshin, B., 2004. Cooperative R&D and firm performance. Research Policy, 33(10): 1477-1492.

Bigliardi, B., Nosella, A., Verbano, C., 2005. Business models in the Italian biotechnology industry: A quantitative analysis. Technovation, 25(11): 1299-1306.

Bijker, W. E., Law, J., 1992. Shaping technology, building society: Studies in sociotechnical change. Cambridge, MA: MIT Press.

BioPartner, 2003. Growth against the tide: The Netherlands Life Sciences Sector Report, Biopartner Network.

BioPartner, 2004. The Netherlands Life Sciences Sector Report 2004: Moving forward, BioPartner Network.

BioPartner, 2005. The Netherlands Life Sciences Sector Report 2005: New challenges ahead, BioPartner Network.

Boomsma, A., 1983. On the robustness of LISREL (maximum likelihood estimation) against small sample size and non-normality. Social Sciences. Groningen, University of Groningen.

Borgatti, S. P., 2002. NetDraw: Graph Visualization Software. Harvard: Analytic Technologies.

Breschi, S., Lissoni, F., Malerba, F., 2003. Knowledge-relatedness in firm technological diversification. Research Policy, 32(1): 69-87.

Brittain, J. W., Freeman, J. H., 1980. Organizational proliferation and density dependent selection, in: J. R. Kimberly and R. H. Miles (Eds.), The organizational life cycle: Issues in the creation, transformation and decline of organizations. San Francisco: Jossey-Bass Publishers.

Burt, R. S., 1997. The contingent value of social capital. Administrative Science Quarterly, 42(2): 339-365.

Burt, R. S., 2000. Decay functions. Social Networks, 22(1): 1-28.

Campbell, N. A., Reece, J. B., Mitchell, L. G., 1999. Biology. Menlo Park, California: Addison-Wesley.

Cantner, U., Pyka, A., 1998. Technological evolution: An analysis within the knowledge-based approach. Structural Change and Economic Dynamics, 9: 85-107.

Chiesa, V., Toletti, G., 2004. Network of collaborations for innovation: The case of biotechnology. Technology Analysis & Strategic Management, 16(1): 73-96.

Christensen, C. M., Raynor, M. E., 2003. The innovator's solution: Creating and sustaining successful growth. Boston: Harvard Business School Press.

Critical I, 2006. Biotechnology in Europe: 2006 Comparative study, EuropaBio.

Crommelin, D. J. A., Sindelar, R. D., 2002. Pharmaceutical Biotechnology: An introduction for pharmacists and pharmaceutical scientists. London Routledge.

Das, T. K., Teng, B. S., 1998. Resource and risk management in the strategic alliance making process. Journal of Management, 24(1): 21-42.

Das, T. K., Teng, B. S., 2000. A resource-based theory of strategic alliances. Journal of Management, 26(1): 31-61.

Deephouse, 1999. To be different or to be the same? It's a question (and theory) of strategic balance. Strategic Management Journal, 20(2): 147-166.

Dongen, M. B. M. v., Derksen, H. T. P., Diemen, A. E. A. R. v., 2005. Eindevaluatie BioPartner-programma. Maarsbergen, InnoTact Consulting, in opdracht van het Ministerie van Economische Zaken.

Doz, Y. L., 1996. The evolution of cooperation in strategic alliances: Initial conditions or learning processes? Strategic Management Journal, 17(Special issue: Evolutionary perspectives on strategy.): 55-83.

Duysters, G. M., 1995. The evolution of complex industrial systems. Maastricht: Maastricht University Press.

Duysters, G. M., Hagedoorn, J., 1998. Technological convergence in the IT industry: The role of strategic technology alliances and technological competencies. International Journal of the Economics of Business., 5(3): 355-368.

Eisenhardt, K. M., Bird Schoonhoven, C., 1996. Resource-based view of strategic alliance formation: Strategic and social effects in entrepreneurial firms. Organization Science, 7(2): 136-150.

Ernst & Young, 2004. Per Aspera Ad Astra "Der steinige Weg zu den Sternen": Deutscher Biotechnologie-Report 2004. Mannheim.

Ernst & Young, 2004. Refocus: The European Perspective Global Biotechnology Report 2004. Cambridge: 54.

Ernst & Young, 2005. Beyond borders: Global Biotechnology Report 2005: 87.

Faber, J., 1988. Consistent estimation of correlations between observed interval variables with skewed distributions. Quality and Quantity, 22(4): 381-392.

Faber, J., 1991. Cooperation and conflict among nations: An application of multi-sample confirmatory factor analysis. Statistica Neerlandica, 45(2): 195-206.

Freeman, C., Carroll, G. R., Hannan, M. T., 1983. The liability of newness: Age dependence in organizational death rates. American Sociological Review, 48(5): 692-710.

Gambardella, A., Torrisi, S., 1998. Does technological convergence imply convergence in markets? Evidence from the electronics industry. Reseach Policy, 27(5): 445-463.

Garud, R., Rappa, M. A., 1994. A socio-cognitive model of technology evolution: The case of cochlear implants.. Organization Science, 5(3): 344-362.

Gassmann, O., Reepmeyer, G., Von Zedtwitz, M., 2004. Leading pharmaceutical innovation. Trends and drivers for growth in the pharmaceutical industry. Berlin: Springer.

Gay, B., Dousset, B., 2005. Innovation and network structural dynamics: Study of the alliance network of a major sector of the biotechnology industry. Research Policy, 34(10): 1457-1475.

Gilsing, V., Nooteboom, B., 2006. Exploration and exploitation in innovation systems: The case of pharmaceutical biotechnology. Research Policy, 35(1): 1-23.

Gilsing, V. A., 2003. Exploration, exploitation and co-evolution in innovation networks. Rotterdam, Erasmus Universiteit.

Grant, R. M., Baden-Fuller, C., 2004. A knowledge accessing theory of strategic alliances. Journal of Management Studies 41(1): 61-84.

Greis, N. P., Dibner, M. D., Bean, A. S., 1995. External partnering as a response to innovation barriers and global competition in biotechnology. Research Policy, 24(4): 609-630.

Gulati, R., 1995. Social structure and alliance formation patterns: A longitudinal analysis. Administrative Science Quarterly, 40(4): 619-652.

Gulati, R., 1998. Alliances and networks. Strategic Management Journal, 19(4): 293-317.

Gulati, R., 1999. Network location and learning: The influence of network resources and firm capabilities on alliance formation. Strategic Management Journal, 20(5): 397-240.

Gulati, R., Gargiulo, M., 1999. Where do interorganizational networks come from? American Journal of Sociology, 104(5): 1439-1493.

Hagedoorn, J., 1993. Understanding the rationale of strategic technology partnering: Interorganizational modes of cooperation and sectorial differences. Strategic Management Journal, 14(5): 371-385.

Hagedoorn, J., 2002. Inter-firm R&D partnerships: An overview of major trends and patterns since 1960. Research Policy, 31(4): 477-492.

Hagedoorn, J., Narula, R., 1996. Choosing organisational modes of strategic technology partnering: International and sectoral differences. Journal of International Business Studies, 27(2): 265-284.

Hall, L. A., Bagchi-Sen, S., 2007. An analysis of firm-level innovation strategies in the US biotechnology industry. Technovation, 27(1-2): 4-14.

Harianto, F., Pennings, M., 1994. Technological convergence and scope of organizational innovation. Reseach Policy, 23(3): 293-304.

Hitt, M. A., Dacin, T., Levitas, E., Arregle, J. L., Borza, A., 2000. Partner selection in emerging and developed market contexts: Resource-based and organizational learning perspectives. The Academy of Management Journal, 43(3): 449-467.

Jolivet, E., Maurice, M., 2006. How markets matter: Radical innovation, societal acceptance, and the case of genetically engineered food, in: J. Hage and M. T. H. Meeus (Eds.), Innovation, science and institutional change: A research handbook. New York: Oxford University Press.

Jöreskog, K. G., Sörbom, D., 1993. LISREL® 8: User's Reference Guide. Chicago: Scientific Software International.

Jöreskog, K. G., Sörbom, D., 1995. PRELISTM: a program for multivariate data screening and data summarization. Chicago: Scientific Software International.

Kash, D. E., Rycroft, R., 2002. Emerging patterns of complex technological innovation. Technological Forecasting and Social Change, 69(6): 581-606.

Khilji, E., Mroczkowski, T., Bernstein, B., 2006. From invention to innovation: Toward developing an integrated innovation model for biotech firms. Journal of Product Innovation Management, 23(6): 528-540.

Kogut, B., 2000. The network as knowledge: Generative rules and the emergence of structure. Strategic Management Journal, 21(3): 405-425.

Lemarié, S., De Looze, M. A., Mangematin, V., 2000. Strategies of European SMEs in biotechnology: The role of size technology and market. Scientometrics, 47(3): 541-560.

Levinthal, D. A., 1998. The slow pace of rapid technological change: Gradualism and punctuation in technological change. Industrial and Corporate Change, 7(2): 217-247.

Lewin, A. Y., Weigelt, C. B., Emery, J. D., 2004. Adaptation and selection in strategy and change: Perspectives on strategic change in organizations, in: M. S. Poole and A. H. v. d. Ven (Eds.), Handbook of organizational change and innovation. Oxford: Oxford University Press.

Malerba, F., Orsenigo, L., 1996. Schumpetarian patterns of innovation are technology-specific. Research Policy, 25(3): 451-478.

Malerba, F., Orsenigo, L., 1999. Technological entry, exit and survival: An empirical analysis of patent data. Research Policy, 28(6): 643-660.

Mazzoleni, R., Nelson, R. R., 1998. The benefits and costs of strong patent protection: a contribution to the current debate. Research Policy, 27(3): 273-284.

McKelvey, M., Rickne, A., Laage-Hellman, J., 2004. The economic dynamics of modern biotechnology. Cheltenham: Edward Elgar.

McKelvey, M. D., 1996. Evolutionary innovations: The business of biotechnology. Oxford: Oxford University Press.

Meeus, M. T. H., Oerlemans, L. A. G., Hage, J., 2001. Sectoral patterns of interactive learning: An empirical exploration of a case in a Dutch region. Technology Analysis & Strategic Management, 13(3): 407-431.

Meeus, M. T. H., Oerlemans, L. A. G., Hage, J., 2004. Industry-public knowledge infrastructure interaction: Intra- and inter-organizational explanations of interactive learning. Industry and Innovation, 11(4): 327-352.

Meyer-Krahmer, F., Schmoch, U., 1998. Science-based technologies: University-industry interactions in four fields. Research Policy, 27(8): 835-851.

Ministry of Economic Affairs, 1999. Action plan life sciences 2000-2004. The Hague, Ministry of Economic Affairs.

Ministry of Economic Affairs, 2003. Life sciences: Een pijler van de Nederlandse kenniseconomie. Den Haag, Cluster Life Sciences, Ministerie van Economische Zaken: 44.

Ministry of Economic Affairs, 2004. Actieplan life sciences: Kansen grijpen, knelpunten aanpakken. Den Haag: 22.

Miotti, L., Sachwald, F., 2003. Co-operative R&D: Why and with whom? An integrated framework of analysis. Research Policy, 32(8): 1481-1499.

Moors, J. J. A., Muilwijk, J., 1975. Steekproeven: een inleiding tot de praktijk. Amsterdam: Agon Elsevier.

Mowery, D. C., Oxley, J. E., Silverman, B. S., 1998. Technological overlap and interfirm cooperation: Implications for the resource-based view of the firm. Research Policy, 27(5): 507-523.

Nelson, R. R., Winter, S. G., 1982. An evolutionary theory of economic change. Cambridge: The Belknap press of Harvard University Press.

Niosi, J., 2003. Alliances are not enough explaining rapid growth in biotechnology firms. Research Policy, 32(5): 737-750.

Nooteboom, B., 1999. Interfirm alliances: Analysis and design. New York: Routledge.

Nooteboom, B., 2000. Learning and innovation in organizations and economies. New York: Oxford University Press.

Nooteboom, B., Vanhaverbeke, W., Duysters, G. M., Gilsing, V., Van den Oort, A., 2007. Optimal cognitive distance and absorptive capacity. Research Policy, In Press.

Nosella, A., Petroni, G., Verbano, C., 2005. Characteristics of the Italian biotechnology industry and new business models: The initial results of an empirical study. Technovation, 25(8): 841-855.

OECD, 2001. Biotechnology statistics in the OECD member countries: compendium of existing national statistics. STI working paper 2001/6, Directorate for Science, Technology and Industry, OECD.

Oliver, A. L., 2001. Strategic alliances and the learning life-cycle of biotechnology firms. Organization Studies, 22(3): 467-489.

Olsson, U., 1979. Maximum likelihood estimation of the polychoric correlation coefficient. Psychometrika, 44: 443-460.

Olsson, U., Drasgow, F., Dorans, N. J., 1982. The polyserial correlation coefficient. Psychometrika, 47: 337-347.

Oosterwijk, H., 2003. Sectoral variations in national systems of innovation: the case of Telecommunication and Modern Biotechnology. Social Sciences. Utrecht, University of Utrecht: 504.

Orsenigo, L., Pammolli, F., Riccaboni, M., 2001. Technological change and network dynamics: Lessons for the pharmaceutical industry. Research Policy, 30(3): 485-508.

Owen-Smith, J., Powell, W. W., 2003. The expanding role of university patenting in the life sciences: Assessing the importance of experience and connectivity. Research Policy, 32(9): 1695-1711.

Owen-Smith, J., Powell, W. W., 2004. Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. Organization Science, 15(1): 5-21.

Penrose, E. T., 1959. The theory of growth of the firm. White Plains, New York: M.E. Sharpe.

Pfeffer, J., Salancik, G. R., 1978. The external control of organisations: A resource dependence perspective. New York: Harper & Row Publishers.

Phan, P. H., Siegel, D. S., Wright, M., 2005. Science parks and incubators: observations, synthesis and future research. Journal of Business Venturing, 20(2): 165-182.

Powell, W. W., 1996. Inter-organizational collaboration in the biotechnology industry. Journal of Institutional and Theoretical Economics, 152(1): 197-219.

Powell, W. W., Koput, K. W., Smith-Doerr, L., 1996. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. Administrative Science Quarterly, 41(1): 116-145.

Powell, W. W., Koput, K. W., White, D. R., Owen-Smith, J., 2005. Network dynamics and field evolution: The growth of interorganizational collaboration in the life sciences. American Journal of Sociology, 110(4): 1132-1205.

Pyka, A., Saviotti, P., 2001. Innovation networks in the biotechnology-based sectors. Discussion papers, Universitaet Augsburg, Institute for Economics.

Rao, H., Singh, J. V., 2001. Organizational speciation as new path creation: Institution building activity in the early automobile and bio-tech industries, in: R. Garud and P. Karnoe (Eds.), Path Dependence and Creation. London: Lawrence Erlbaum, 243-269.

Reuer, J. J., Zollo, M., Singh, H., 2002. Post-formation dynamics in strategic alliances. Strategic Management Journal, 23(2): 135-151.

Roijakkers, A. H. W., 2003. Inter-firm cooperation in high-tech industries: A study of R&D partnerships in pharmaceutical biotechnology. Maastricht: Universitaire Pers Maastricht.

Roijakkers, A. H. W., Hagedoorn, J., 2006. Inter-firm R&D partnering in pharmaceutical biotechnology since 1975: Trends, patterns and networks. Research Policy, 35(3): 431-446.

Rosenberg, N., 1982. Inside the black box: Technology and economics. Cambridge Cambridge University Press.

Sager, B., 2001. Scenarios on the future of biotechnology. Technological Forecasting & Social Change, 68(2): 109-129.

Sakakibara, M., 2002. Formation of R&D consortia: Industry and company effects. Strategic Management Journal, 23(11): 1033-1050.

Salancik, G. R., 1995. Review: Wanted: A good network theory of organization. Administrative Science Quarterly, 40(2): 345-349.

Santos, F. M., 2003. The coevolution of firms and their knowledge environment: Insights from the pharmaceutical industry. Technological Forecasting & Social Change, 70(7): 687-715.

Saviotti, P., De Looze, M. A., Maupertuis, M. A., 2005. Knowledge dynamics, firm strategy, mergers and acquisitions in the biotechnology-based sectors. Economics of Innovation and New Technology, 14(1): 103-124.

Seabright, M. A., Levinthal, D. A., Fichman, M., 1992. Role of individual attachments in the dissolution of interorganizational relationships. The Academy of Management Journal, 35(1): 122-160.

Simon, H. A., 1957. Models of man: social and rational. New York: John Wiley and Sons.

Singh, J. V., Tucker, D. J., House, R. J., 1986. Organizational legitimacy and the liability of newness. Administrative Science Quarterly, 31(2): 171-193.

Smith Ring, P., Van de Ven, A. H., 1992. Structuring cooperative relationships between organizations. Strategic Management Journal, 13(7): 483-498.

Smith Ring, P., Van de Ven, A. H., 1994. Developmental processes of cooperative interorganizational relationships. The Academy of Management Review, 19(1): 90-118.

Soh, P. H., Roberts, E. B., 2003. Networks of innovators: A longitudinal perspective. Research Policy, 32(9): 1569-1588.

Stinchcombe, A. L., 1965. Social Structure and Organizations, in: J. G. March (Eds.), Handbook of Organizations. Chicago: Rand McNally & Company, 142-193.

Stoelhorst, J. W., 1997. In search of a dynamic theory of the firm. Twente, University of Twente: 415.

Stuart, T. E., 1998. Network positions and propensities to collaborate: An investigation of strategic alliance formation in a high-technology industry. Administrative Science Quarterly, 43(3): 668-698.

Stuart, T. E., Hoang, H., Hybels, R. C., 1999. Interorganizational endorsements and the performance of entrepreneurial ventures. Administrative Science Quarterly, 44(2): 315-349.

Teece, D., 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Research Policy, 15: 285-305.

Teece, D., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strategic Management Journal, 18(7): 509-533.

Terziovski, M., Morgan, J. P., 2006. Management practices and strategies to accelerate the innovation cycle in the biotechnology industry. Technovation, 26(5-6): 545-552.

Thumm, N., 2004. Strategic patenting in biotechnology. Technology Analysis & Strategic Management, 16(4): 529-538.

Tidd, J., Bessant, J., Pavitt, K., 2001. Managing Innovation: Integrating Technological, Market and Organizational Change. Chichester: John Wiley & Sons.

Uzzi, B., 1997. Social Structure and Competition in Interfirm Networks: The Paradox of Embeddedness. Administrative Science Quarterly, 42(1): 35-67.

Van de Ven, A. H., 1976. On the nature, formation and maintenance of relations among organizations. The Academy of Management Review, 1(4): 24-36.

Van de Ven, A. H., Polley, D. E., Garud, R.,Venkataraman, S., 1999. The Innovation Journey. New York/Oxford: Oxford University Press.

Van Lente, H., 2006. Prospective structures of science and science policy, in: J. Hage and M. T. H. Meeus (Eds.), Innovation, science and institutional change: A research handbook. New York: Oxford University Press.

Van Merkerk, R. O., Robinson, D. K. R., 2006. Characterizing the emergence of a technological field: Expectations, agendas and networks in lab-on-a-chip technologies. Technology Analysis & Strategic Management, 18(3): 411-428.

Vanhaverbeke, W., Noorderhaven, N. G., 2001. Competition between alliance blocks: The case of the RISC Microprocessor technology. Organization Studies, 22(1): 1-30.

Walsh, G., 2005. Biopharmaceuticals: Recent approvals and likely directions. Trends in Biotechnology, 23(11): 553-558.

Wasserman, S., Faust, K., 1994. Social Network Analysis. Cambridge: Cambridge University Press.

Watts, D. J., Strogatz, S. H., 1998. Collective dynamics of 'small world' networks. Nature, 393: 440-442.

Wernerfelt, B., 1984. A resource-based view of the firm. Strategic Management Journal, 5(2): 171-180.

Willemstein, L., Van der Valk, T., Meeus, M. T. H., 2007. Dynamics in business models: An empirical analysis of medical biotechnology firms in the Netherlands. Technovation, 27(4): 221-232.

Wonnacott, T. H., Wonnacott, R. J., 1990. Introductory Statistics. New York: John Wiley & Sons.

Yasuda, H., 2005. Formation of strategic alliances in high-technology industries: Comparative study of the resource-based theory and the transaction cost theory. Technovation, 25(7): 763-770.

Summary

Organisations active in the life sciences sector make use of developments in modern biotechnology. Modern biotechnology constitutes a broad field of enabling technologies impacting several different industrial sectors, including pharmaceuticals, chemicals, agriculture and food. Due to the potentially pervasive character of this set of enabling technologies, their development is considered to be highly important in stimulating sustainable future economic development (Ministry of Economic Affairs, 2004). However, this field is still in a nascent stage of development and can thus be considered emerging. New technological developments succeed one another rapidly, generating uncertainty about which technological opportunities to seize, and lead to the distribution of knowledge and competences across firms.

New firms founded on the basis of promising inventions within this emerging technological field are susceptible to both the liability of newness and smallness (Freeman et al., 1983). A lack of external legitimacy has been referred to as the general cause for these liabilities, indicating the importance of improving this external legitimacy of the firm (Singh et al., 1986). Engaging in partnering can contribute to this (Stuart et al., 1999; Baum et al., 2000).

Both the overall characteristics of biotechnology as an emerging technological field, as well as the age and size of firms operating within it, make organisations inclined to engage in partnering. However, both of these technological and organisational characteristics may also be conceived as reducing the likelihood of a firm to find other organisations interested in collaboration as they generate uncertainty with regard to the chances of the firm's survival. The aim of this thesis is therefore to address the factors that contribute to the ability of technology-based firms active in an emerging technological field to collaborate with other organisations. The empirical focus is on Dutch dedicated life sciences firms (DDLSFs). The main research questions are: *How can developments in the macro-level context of partnering by DDLSFs, consisting of technology dynamics and network dynamics, be characterised in the period 2000-2004?* And on the micro-level: *What factors related to resource-based inducements and opportunities as well as to structural sociological opportunities contribute to explaining interorganisational partnering by DDLSFs on the micro-level?*

Data on the same population of firms are used to address the different aspects contained in these research questions. This makes it possible to relate the findings on these different aspects to each other, which constitutes the primary contribution of this thesis. Most of the data used to answer the research question were obtained from the annual written survey conducted in the name of the BioPartner Network by means of a questionnaire distributed among DDLSFs. In this thesis, the editions of 2002 and 2004 are primarily focused on given that 2002 was the first year in which the questionnaire was relatively comprehensive since the establishment of the BioPartner Network in 2000. Additional sources of data used include firms' websites and interviews with the managers of firms.

This thesis consists of four empirical chapters that subsequently address technology dynamics (Chapter 2), network dynamics (Chapter 3), resource-based explanations for partnering (Chapter 4) and processes of partner search (Chapter 5).

The aim of Chapter 2 is twofold. First of all, it aims to develop a method for studying technology dynamics in an emerging technological field. Secondly, it aims to apply this method to the case of Dutch dedicated life sciences firms. We focused on the in-house technologies of firms at the time of their founding and only include start-ups in the analysis. Contrary to most studies describing technology dynamics, we have not made use of patents but instead focused on technologies in use, information about which was derived from the websites of the relevant firms. We developed a conceptualisation of technology dynamics along two lines: developments in the diversity of subsequent populations of newly founded firms, and the specific technological foci of individual firms in terms of being specialised or combining different technological (sub)fields. In the period from 2000 to 2004, the analysis shows that on the level of the population of newly founded firms the technological diversity increased rather than decreased over time: the number of fields covered by this population increased slightly, and over time these different fields became slightly more equally covered by the firms. On the level of the firm it shows that many firms are specialists, either working on one technological subfield or combining technological subfields belonging to the same main technological field.

Chapter 3 focuses on the level of the network of collaborations of DDLSFs, and the development of this network from 2002 to 2004. It shows that Dutch research institutes are at the centre of this network as several of them have relationships with multiple DDLSFs. In 2002, as well as in 2004, there were only a few relationships between DDLSFs. As different components of the network became connected the reachability of the nodes within the network improved from 2002 to 2004. The diameter of the network grows, indicating that while the reachability of the nodes in the network improves, the network *stretches out.* While, according to the distributional properties of the indegrees of the nodes, the network became slightly more structured from 2002 to 2004, the relationships the network comprises of showed a high degree of volatility, at least with regard to the extent to which partners are believed to be important. This volatility of individual relationships was also reflected in the connectedness of the hubs. While the hubs in the networks of 2002 and 2004 were research institutes, different research institutes are most central in 2002 and in 2004.

The main findings of Chapter 4 concern firm-level explanatory variables for the partnering rate of DDLSFs that have been in business for up to 5 years. Several resource-related variables were incorporated in a sequential model that was tested. In choosing these variables, we focused on resources that are perceived to have reputation- and visibility-enhancing effects, namely patents and venture capital acquisition. We also included variables reflecting business development and the number of managers of the firm, the latter indicating the connectedness of the firm within its environment. Three variables were found to influence the partnering rate directly, namely the number of patents owned by the firm (negative), its number of employees at the end of the previous year (positive) and the amount of venture capital the firm has acquired (positive). Indirectly, business development in terms of the change in turnover and the number of managers also (positively) affected the partnering rate of the firm. A possibly reputation-related effect of patent acquisition on the partnering rate was found to be indirect; the number of patents of the firm positively influenced venture capital acquisition, which in turn had a positive influence on the partnering rate.

In Chapter 5, inducements and opportunities for partnering of DDLSFs are set out on the level of the partnership and processes of partner search are examined. This chapter shows that access to technological knowledge and facilities is the primary inducement and opportunity of DDLSFs for engaging in R&D partnering, both with research institutes and other firms. In partnerships with research institutes, DDLSFs also provide access to resources related to commercialisation (opportunity DDLSF), whereas in partnerships with other firms these firms also provide access to their resources related to commercialisation (inducement DDLSF). Finding partners can be done by making use of several different sources of information; these include networks of contacts, internal knowledge and events. These networks of contacts include previous partners but other types of contacts, such as those resulting from former employment of the managers, are of greater importance. Two aspects that were found to potentially structure the large variety in partner search processes are the relative establishedness of DDLSFs and whether or not they have acquired a patent. There seems to be an evolution in the extent to which firms are inclined to initiate partnerships: firms without patents and unestablished firms seem to be more inclined to accept invitations for partnering with other organisations, while firms with patents and more established firms are more often likely to initiate partnerships and search for partners themselves. Also, the inducements of the more established firms and firms with patents seem to be more directed toward commercialisation-related resources than those of unestablished firms and firms without patents.

To summarise, by addressing partnering this thesis has focused on technology dynamics, network dynamics, firm resources from which inducements and opportunities for partnering were derived, and processes of finding partners. Relating the findings on macro-level developments of technology and networks within the sector to partnering residing at the micro-level constitutes the main contribution of this thesis. In this respect, several implications can be derived from this research.

First of all, the increasing technological diversity of newly founded firms makes it difficult for all sorts of actors, including policy makers, established firms and venture capitalists to decide which technological opportunities to support or develop further.

Furthermore, research institutes were found to be the hubs in the network comprised of partnerships of DDLSFs. However, as has been shown in Chapter 4 of this thesis, business development, both prior and current, and thus exploitation and growth are important for partnering. Engaging in collaboration primarily with research institutes might not contribute as much to exploitation as collaboration with firms.

On the micro-level, the primary inducement of DDLSFs for partnering is to gain access to the technological knowledge of its partner (Chapters 4 and 5). However, some aspects were found to interfere with this seemingly rational structuring of partnering based on the complementarity of technological knowledge. On the level of the firm, business development, both prior and current, was found to positively influence the partnering rate of DDLSFs. This implies that relatively more positive prior and current business development provides a DDLSF with opportunities for partnering. Such a positive effect on partnering was also exerted by the acquisition of venture capital.

With regard to the search for partners, satisficing behaviour seems to be exhibited by the DDLSFs involved (Simon, 1957) (Chapter 5). This finding indicates that for many DDLSFs partnering can be characterised by trial and error learning, rather than adhering to a strategy that has been determined beforehand. This might significantly influence the subsequent chance of success of the established partnerships. The high volatility of partnerships found in Chapter 3 of this thesis could be related to this: firms either decide to partner only for a limited period, or these partnerships are discontinued prematurely. The general tendency to think that engaging in partnering is good for organisations is based on the idea that partnerships can be used to reduce the *performance risk* of projects, which refers to the risk that the project aims will not be achieved (Das and Teng, 1998). If partnering is based on trial and error, the extent to which the performance risk of projects is reduced may be limited.

Finally, while the partnership-level analysis conducted in Chapter 5 focused solely on search processes leading to the formation of R&D partnerships, this study does not provide insight into the extent to which organisations are inclined to accept or reject certain invitations for partnering, as this contributes to the study of selection of partners and partnerships. Also, the perspectives of all organisations involved in a partnership should be addressed explicitly in future research.

Samenvatting

Technologiedynamiek, Netwerkdynamiek en Samenwerking
De Casus van Nederlandse 'Dedicated' Life Sciences Bedrijven

Organisaties die opereren in de life sciences sector maken gebruik van ontwikkelingen op het gebied van de moderne biotechnologie. Moderne biotechnologie is een breed veld van technologieën, die toegepast kunnen worden in verscheidene industriële sectoren, waaronder farmacie, chemie, landbouw en voeding. Mede doordat moderne biotechnologie in vele sectoren toepasbaar is wordt verdere ontwikkeling hiervan zeer belangrijk gevonden voor het bereiken van duurzame economische ontwikkeling in de toekomst (Ministry of Economic Affairs, 2004). Het life sciences veld verkeert echter nog in een vroeg stadium van ontwikkeling waarin technologieën elkaar snel opvolgen. Dit creëert onzekerheid met betrekking tot het te verwachten succes van technologieën. Deze onzekerheid draagt eraan bij dat bedrijven geneigd zijn gebruik te maken van samenwerkingsverbanden met andere organisaties om toegang te krijgen tot complementaire kennis in plaats van zich deze kennis eigen te maken. Dit leidt tot een verspreiding van technologische kennis over organisaties.

Bedrijven die opgericht worden op basis van veelbelovende uitvindingen behorend tot dit opkomende technologische veld hebben een relatief grote kans op falen, zowel door hun jonge leeftijd als hun beperkte grootte (Freeman et al., 1983). Een belangrijke reden hiervoor is het gebrek aan externe legitimiteit dat deze bedrijven karakteriseert (Singh et al., 1986). Het aangaan van samenwerkingsverbanden met andere organisaties kan bijdragen aan het opbouwen van legitimiteit (Stuart et al., 1999; Baum et al., 2000).

Zowel de karakteristieken van de life sciences als opkomend veld, als de leeftijd en grootte van bedrijven die opereren in dit veld leiden er dus toe dat bedrijven geneigd zijn samenwerkingsverbanden met anderen aan te gaan. Echter, deze karakteristieken verkleinen tegelijkertijd de kans dat een bedrijf andere organisaties kan vinden die geïnteresseerd zijn in samenwerking, omdat deze karakteristieken de overlevingskansen van een bedrijf onzeker maken.

Het doel van dit proefschrift is om factoren te identificeren die bijdragen aan de mogelijkheden van technologie-intensieve bedrijven die actief zijn in een opkomend veld om samenwerkingsverbanden met andere organisaties aan te gaan. Dit proefschrift richt zich op de casus van Nederlandse 'dedicated' life sciences bedrijven (DDLSFs), dat wil zeggen bedrijven die zich voor het grootste deel van hun activiteiten specifiek richten op de life sciences. De centrale onderzoeksvragen zijn: *hoe kunnen ontwikkelingen in de macrocontext van samenwerking door DDLSFs, bestaande uit technologiedynamiek en netwerkdynamiek, gekarakteriseerd worden in de periode van 2000 tot 2004?* En op het bedrijfsniveau: *welke factoren, gerelateerd aan de hulpbronnen van het bedrijf alsmede structureel sociologische aspecten, dragen bij aan het verklaren van interorganisationele samenwerking door DDLSFs op microniveau?*

Bij het adresseren van de verschillende aspecten die onderdeel zijn van de onderzoeksvragen wordt data over dezelfde populatie bedrijven gebruikt. Dit maakt het mogelijk om de bevindingen ten aanzien van deze verschillende aspecten met elkaar in verband te brengen, hetgeen de primaire bijdrage van dit proefschrift vormt. Het merendeel van de data die gebruikt zijn in dit proefschrift zijn afkomstig van een jaarlijkse schriftelijke enquête, uitgevoerd in naam van het BioPartner Network en verspreid onder DDLSFs. De nadruk van dit proefschrift ligt hierbij op de edities van 2002 en 2004 omdat de enquête sinds 2002 in uitgebreide vorm bestaat. Additionele bronnen van data zijn websites van DDLSFs en interviews met managers van die bedrijven.

Dit proefschrift omvat vier empirische hoofdstukken die opeenvolgend technologiedynamiek (hoofdstuk 2), netwerkdynamiek (hoofdstuk 3), hulpbrongerelateerde verklaringen voor samenwerking (hoofdstuk 4) en processen van het vinden van partners (hoofdstuk 5) adresseren.

Het doel van hoofdstuk 2 is tweeledig. Ten eerste is het doel een methode te ontwikkelen voor het bestuderen van technologiedynamiek in een opkomend veld. Ten tweede heeft het als doel deze methode toe te passen op de casus van DDLSFs. We hebben ons hierbij gericht op de technologieën waar startende bedrijven over beschikken. Informatie hierover werd, in tegenstelling tot in veel andere studies, niet afgeleid uit patentgegevens, maar uit informatie van websites van DDLSFs.

In de ontwikkelde methode hebben we zowel de technologische diversiteit van opeenvolgende populaties van nieuw opgerichte bedrijven meegenomen, als de specifieke portfolio's van individuele bedrijven behorend tot die populaties. Bij dit laatste gaat het erom of bedrijven gespecialiseerd zijn of juist technologische (sub-)velden met elkaar combineren. In de periode van 2000 tot 2004 laat deze analyse zien dat de technologische diversiteit van opeenvolgende populaties van nieuw opgerichte bedrijven eerder toegenomen is dan afgenomen: het aantal velden waarop deze bedrijven actief waren nam toe terwijl de bedrijven zich meer gelijk verdeelden over die verschillende technologische velden. Op het niveau van het individuele bedrijf laat de analyse zien dat veel bedrijven gespecialiseerd zijn en werken op één technologisch subveld, of technologische subvelden combineren die onderdeel zijn van hetzelfde hoofdveld.

Hoofdstuk 3 richt zich op het netwerk van samenwerkingsverbanden van DDLSFs, en de ontwikkeling van dit netwerk van 2002 tot 2004. Het hoofdstuk laat zien dat Nederlandse onderzoeksinstituten zich in het centrum van dit netwerk bevinden. Zowel in 2002 als in 2004 waren er slechts enkele samenwerkingsverbanden tussen DDLSFs onderling.

In zijn totaliteit raakte het netwerk van 2002 tot 2004 meer verbonden, wat leidde tot een toename van de bereikbaarheid van de bedrijven in het netwerk. De diameter van het netwerk nam toe, wat impliceert dat het netwerk zich, terwijl het meer verbonden raakte, uitstrekte. Hoewel het netwerk van 2002 tot 2004 meer gestructureerd raakte, waren de individuele relaties in het netwerk zeer volatiel, tenminste alwaar het gaat over het belang dat wordt gehecht aan bepaalde partners. Deze volatiliteit kwam ook tot uitdrukking in de centrale knooppunten in het netwerk: in beide jaren waren Nederlandse onderzoeksinstituten de centrale knooppunten, maar de specifieke instituten die in 2002 en 2004 het meest centraal waren verschilden.

De belangrijkste bevindingen van het vierde hoofdstuk hebben betrekking op verklarende variabelen voor het aantal samenwerkingsverbanden van DDLSFs die maximaal 5 jaar bestaan.

Verscheidene hulpbrongerelateerde variabelen werden opgenomen in het te toetsen model. Bij de keuze van deze variabelen werd met name gericht op variabelen waarvan gesteld kan worden dat deze effect hebben op de reputatie van het bedrijf, hetgeen nauw verbonden is met haar externe legitimiteit. Het gaat hierbij om het aantal verkregen patenten en de hoeveelheid risicokapitaal dat door het bedrijf is verkregen. Ook hebben we variabelen meegenomen die betrekking hebben op de ontwikkeling van het bedrijf en haar aantal managers. Daarbij kan dit laatste gezien worden als een reflectie van de verbondenheid van het bedrijf met haar omgeving.

Er werden drie variabelen gevonden die een directe invloed hadden op het aantal samenwerkingsverbanden van een DDLSF, namelijk het aantal patenten van het bedrijf (negatieve invloed), haar aantal medewerkers aan het eind van het voorgaande jaar (positieve invloed) en de hoeveelheid risicokapitaal dat door het bedrijf is verkregen (positieve invloed). Indirect waren ook de ontwikkeling van het bedrijf en haar aantal managers van invloed op het aantal samenwerkingsverbanden (beide positief). Een mogelijk reputatiegerelateerd effect van het aantal verkregen patenten op samenwerking werd ook gevonden, maar dan indirect: het aantal patenten van een DDLSF had een positieve invloed op het verkrijgen van risicokapitaal door deze DDLSF, wat weer een positieve invloed had op het aantal samenwerkingsverbanden.

Hoofdstuk 5 richt zich op het niveau van het individuele samenwerkingsverband en besteedt aandacht aan het proces van het zoeken naar partners. Tevens worden factoren die samenwerking mogelijk maken en factoren die bedrijven aanzetten tot samenwerking behandeld. In dit hoofdstuk wordt aangetoond dat het verkrijgen van toegang tot technologische kennis en faciliteiten het primaire motief is voor DDLSFs om samenwerkingsverbanden op het gebied van onderzoek en ontwikkeling aan te gaan, zowel met andere bedrijven als met onderzoeksinstituten. In samenwerkingsverbanden met andere bedrijven kunnen DDLSFs tevens profiteren van hun hulpbronnen op het gebied van commercialisatie. In samenwerkingsverbanden met onderzoeksinstituten voorzien DDLSFs deze onderzoeksinstituten juist van hulpbronnen gerelateerd aan de commercialisatie van kennis.

Het zoeken naar partners vindt plaats met gebruik van verschillende informatiebronnen, waaronder netwerken van contacten, interne kennis van het bedrijf en deelname aan bijeenkomsten en evenementen. Vroegere partners maken ook deel uit van netwerken van contacten, maar andere typen contacten, bijvoorbeeld voormalige werkgevers van de managers, zijn voor het vinden van partners van groter belang.

Er werden twee aspecten gevonden die de grote variëteit in processen van het vinden van partners structureerden, namelijk de mate waarin de DDLSF als gevestigd kan worden gezien en of de DDLSF wel of geen patent heeft verkregen. Er lijkt in dit opzicht sprake van een verschuiving in de mate waarin een DDLSF zelf geneigd is het initiatief te nemen tot het oprichten van een partnership: bedrijven die nog minder gevestigd zijn en nog geen patenten hebben zijn eerder geneigd uitnodigingen van anderen om samen te werken te accepteren, terwijl bedrijven die meer gevestigd zijn en wel patenten hebben eerder zelf het initiatief nemen tot het zoeken van een partner. Tevens blijken de drijfveren van meer gevestigde bedrijven en bedrijven met patenten meer gericht te zijn op het bevorderen van commercialisatie van kennis dan die van minder gevestigde bedrijven en bedrijven zonder patenten.

Samenvattend heeft dit proefschrift in het behandelen van samenwerking door DDLSFs met name aandacht besteed aan technologiedynamiek, netwerkdynamiek, de hulpbronnen van bedrijven die de mate van samenwerking kunnen beïnvloeden, en processen van het vinden van partners. Het relateren van technologiedynamiek en netwerkdynamiek aan processen van partnering op microniveau vormt de primaire bijdrage van dit proefschrift. In dit opzicht kunnen uit dit proefschrift verscheidene implicaties worden afgeleid.

Allereerst maakt de toename in de technologische diversiteit van nieuw opgerichte bedrijven het moeilijk voor allerlei soorten actoren, waaronder beleidsmakers, gevestigde bedrijven en kapitaalverstrekkers om te beslissen op welke technologische velden zij het beste kunnen inzetten. Vervolgens werden kennisinstellingen geïdentificeerd als knooppunten in het netwerk van samenwerkingsverbanden. In hoofdstuk 4 van dit proefschrift werd echter aangetoond dat bedrijfsontwikkeling, dat wil zeggen exploitatie en groei, van belang is voor het aangaan van samenwerkingsverbanden. Het aangaan van samenwerkingsverbanden met kennisinstellingen zou hieraan een kleinere bijdrage kunnen leveren dan samenwerking met andere bedrijven. Dit alles maakt de overlevingskansen van de bedrijven onzeker.

In zowel hoofdstuk 4 als 5 werd gevonden dat de primaire reden voor DDLSFs om samen te werken het verkrijgen van toegang tot de technologische kennis van de partner is. Echter, er zijn in dit proefschrift ook factoren geïdentificeerd die dit schijnbare rationele proces van samenwerking lijken te verstoren. Allereerst zijn dat op het bedrijfsniveau een positieve bedrijfsontwikkeling en het verkrijgen van risicokapitaal die maken dat DDLSFs in staat zijn om samen te werken. Met betrekking tot het vinden van partners lijken met name minder gevestigde DDLSFs genoegen nemen met de aan hen aangeboden mogelijkheden tot samenwerking (Simon, 1957) (Chapter 5). Deze bevinding impliceert dat samenwerking voor DDLSFs een leerproces is en niet perse gebaseerd op een van tevoren uitgedachte strategie. Dit zou invloed kunnen hebben op de kans van slagen van de samenwerking. De grote mate van volatiliteit van samenwerkingsverbanden die in hoofdstuk 3 werd gevonden kan hiermee in verband staan: ofwel besluiten bedrijven van tevoren slechts voor beperkte tijd een samenwerkingsverband aan te gaan, ofwel worden samenwerkingsverbanden voortijdig beëindigd.

De algemene aanname dat het deelnemen aan samenwerkingsverbanden een positieve invloed heeft op de bedrijfsprestaties is gebaseerd op het idee dat samenwerking de kans van slagen van een project kan vergroten (Das and Teng, 1998). Echter, als het kiezen van partners gebaseerd is op een leerproces, dan zou de invloed van samenwerking op de kans van slagen van het project beperkt kunnen zijn. De analyse hiervan valt buiten de focus van dit proefschrift en is daarom onderdeel van vervolgonderzoek. Hierbij komt nog dat, omdat de analyse op het niveau van individuele samenwerkingsverbanden uitgevoerd in hoofdstuk 5 zich alleen gericht heeft op zoekprocessen die hebben geleid tot het oprichten van samenwerkingsverbanden, deze analyse geen inzicht geeft in de mate waarin bedrijven geneigd zijn uitnodigingen voor samenwerking te accepteren dan wel af te slaan. Vervolgonderzoek zou ook hieraan aandacht kunnen besteden omdat dit verder bijdraagt aan de studie naar de selectie van potentiële partners en samenwerkingsverbanden. Tevens zou er in vervolgonderzoek expliciet aandacht besteed moeten worden aan de perspectieven van alle organisaties die deelnemen aan een samenwerkingsverband.

Dankwoord

Na ruim vier jaar ploeteren kom ik dan nu eindelijk toe aan de laatste sectie van mijn proefschrift. Veel mensen hebben, in meer of mindere mate bewust, bijgedragen aan het feit dat ik deze sectie mag schrijven.

Allereerst de organisaties en mensen die de meer praktisch en direct proefschriftgerelateerde ondersteuning van mij hebben verzorgd. Zonder de gegevens die ik deels heb verkregen van en deels verzameld in samenwerking met het BioPartner Netwerk en de Life Sciences groepen van het Ministerie van Economische Zaken en SenterNovem was het schrijven van dit proefschrift niet mogelijk geweest. Hierbij wil ik met name Haifen Hu, Ward Mosmuller, Peter van den Berg en Laura Vis bedanken voor de prettige samenwerking. Linda, bedankt voor je hulp bij het houden van de interviews. Ook wil ik managers van bedrijven die ik heb geïnterviewd bedanken voor hun bijdrage. Ik heb het inspirerend en ook gewoon erg leuk gevonden om te doen. Femke, bedankt voor de tijd die je hebt gestoken in het corrigeren van het Engels.

Vervolgens mijn promotor en copromotoren. Marius, Jan en Ellen bedankt voor het delen van jullie inzichten, waarmee jullie mij steeds een stapje verder hebben gebracht. Marius, bedankt voor je betrokkenheid bij mijn aio-traject, ook na je overstap naar de Universiteit Tilburg. Jan, ik heb veel geleerd van onze nauwe samenwerking aan hoofdstukken 3 en 4 van mijn proefschrift, mijn dank daarvoor. Ellen, ik ben jou, naast je inhoudelijke begeleiding, met name dankbaar voor je steun en het bewaken van het proces in de laatste maanden van mijn aio-traject. Het heeft mij vertouwen gegeven in een goede afronding.

Verder wil ik al mijn collega's bij NW&I bedanken voor de fijne werksfeer die zij voor mij creëerden. Ondanks dat de groep in de vier jaar dat ik er nu gezeten heb flink is gegroeid, heb ik het steeds ervaren als het 'warme nest' waar Ruud het wel eens over heeft. Ik heb genoten van alle gezellige etentjes en spontane borrels!
Floortje, bedankt voor het inroepen van mijn hulp bij het afronden van je onderwijs. Het heeft mij de rust gegeven om daarnaast mijn proefschrift af te ronden. Ineke en Annemarieke, bedankt voor jullie hulp bij van alles en nog wat, en de gezellige praatjes tussendoor.
Alle (oud-)promovendi van NW&I: bedankt voor de gezelligheid en het fijne uitblazen op de squashbaan en het voetbalveld! Ik moet eerlijk zeggen dat ik me er nog steeds over verbaas dat met name deze laatste activiteit niet meer directe 'slachtoffers' heeft geëist dan de pink van Rens en de enkel van Frank (of vergeet ik iets?). Rutger, als mijn kamergenoot heb jij vier jaar lang lief en leed mee gekregen van mijn promotie onderzoek en mijn wereld daarbuiten. We hebben in die tijd erg veel gelachen (oké, oké, in de loop der tijd zijn de grappen iets cynischer geworden), en ik vind onze broodjes knakworst en de kersttoptien nog altijd legendarisch (het gaat voor ons beiden een probleem worden om een nieuwe kamergenoot te vinden die het ook trekt om een maand lang Sky Radio te luisteren…). Bedankt voor je gezelligheid en dat je me wilt

ondersteunen als paranimf! Maryse, bedankt voor je eindeloze vrolijkheid en behulpzaamheid. Ik vond het erg fijn om met jou in 'hetzelfde schuitje' te zitten (tegelijkertijd promoveren, samen onderwijs geven). Ineke, je bent mijn 'heidagen-maatje' (hoe moet dat dit jaar?). Bedankt voor de memorabele borrels, en ik ga ervan uit dat we er daar nog wel meer van zullen hebben. Je bent eregast in de late uurtjes na mijn promotiefeest.

Ik wil mijn vrienden bedanken voor de momenten van afleiding tijdens mijn onderzoek. Iedereen bedankt voor de gezellige etentjes, feestjes en weekendjes weg! In het bijzonder bedank ik de 'harde kern' van Het Neutje en De Poort: Jan-Frens, Maarten en Wouter, bedankt voor de gezellige avonden met de altijd mooie discussies. Jolanda, ik vind het een fijn idee dat jij me tijdens mijn promotie wilt vergezellen als paranimf. Bedankt voor je gezelligheid en steun. Manja en Adinda, ik ben er stilletjes trots op dat, sinds ik tegenover het zwembad woon, we daar nauwelijks meer zijn geweest en onze sportavond zonder veel ophef hebben veranderd in een avond met vooral lekker eten en bijkletsen. Bedankt voor de afleiding die ik heb gevonden in onze gefocuste gesprekken over al dan niet politiek correcte oplossingen voor belangrijkere problemen in deze wereld dan de afronding van mijn proefschrift.

Pap en mam, in jullie nuchterheid (pap) en doorzettingsvermogen (mam) heb ik als aio steeds een goed voorbeeld kunnen zien. Jullie en Marianne wil ik bedanken voor het bijna als vanzelfsprekend lijkende vertrouwen dat jullie altijd in mij laten blijken als ik ergens aan begin.

Tenslotte weet ik zeker dat er, na mijzelf, niemand zo blij is met de afronding van mijn proefschrift als jij, Dennis. Natuurlijk ben ik je dankbaar voor je praktische hulp (zeker bij het maken van figuur voor de kaft), maar ik wil je vooral bedanken voor je steun en warmte. Bedankt voor dat je er bent!

Tessa van der Valk
Utrecht, augustus 2007

Curriculum Vitae

Tessa van der Valk was born in Gouda, the Netherlands, on 3 March 1980. She completed her secondary education at the 'Goudse Scholengemeenschap' in 1998. Also in this year, she started her university education at Utrecht University. In 2002 she obtained her masters degree in Science and Innovation Management, with a specialisation in the field of Medical Biotechnology, after finishing an internship at the Dutch National Institute for Public Health and the Environment (RIVM). In the spring of 2003 she started working on her PhD at the department of Innovation and Environmental Sciences at Utrecht University. She will remain working there for most of the academic year of 2007-2008, as an assistent professor.

NEDERLANDSE GEOGRAFISCHE STUDIES / NETHERLANDS GEOGRAPHICAL STUDIES

325 T DIETZ, P HOEKSTRA & F THISSEN (eds) The Netherlands and the North Sea; Dutch geography 2000-2004 -- Utrecht/Amsterdam 2004: Knag/IGU Section The Netherlands. 158 pp, 27 figs, 4 tabs. ISBN 90-6809-364-9, Euro 29,00

326 C P J M VAN ELZAKKER The use of maps in the exploration of geographic data -- Utrecht/Enschede 2004: Knag/Faculteit Geowetenschappen Universiteit Utrecht/International Institute for Geo-Information Science and Earth Observation. 208 pp, 46 figs, 11 tabs. ISBN 90-6809-365-7, Euro 26,50

327 N M GRUNNET Morphodynamics of a shoreface nourishment in a barred nearshore zone -- Utrecht 2004: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 158 pp, 53 figs, 17 tabs. ISBN 90-6809-366-5, Euro 22,50

328 C A BLOK Dynamic visualization variables in animation to support monitoring of spatial phenomena -- Utrecht/Enschede 2005: Knag/Faculteit Geowetenschappen Universiteit Utrecht/International Institute for GeoInformation Science and Earth Observation. 188 pp, 31 figs, 12 tabs. ISBN 90-6809-367-3, Euro 23,00

329 A E BROUWER Old firms in the Netherlands; The long-term spatial implications of firms' identities and embeddedness -- Utrecht/Groningen 2005: Knag/Faculteit der Ruimtelijke Wetenschappen Rijksuniversiteit Groningen. 270 pp, 46 figs, 26 tabs. ISBN 90-6809-369-X, Euro 27,00

330 J SPIJKER Geochemical patterns in the soils of Zeeland; Natural variability versus anthropogenic impact -- Utrecht 2005: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 205 pp, 54 figs, 36 tabs. ISBN 90-6809-370-3, Euro 22,40

331 I MARIOTTI Firm relocation and regional policy; A focus on Italy, the Netherlands and the United Kingdom -- Utrecht/Groningen 2005: Knag/Faculteit der Ruimtelijke Wetenschappen Rijksuniversiteit Groningen. ca 278 pp. ISBN 90-6809-371-1, Euro 28,00

332 F VAN SOEST Factors determining location and species composition of wet grassland in Southwest England -- Utrecht/Groningen 2005: Knag/Faculteit der Ruimtelijke Wetenschappen Rijksuniversiteit Groningen. ca 240 pp + cd-rom, 110 figs, 42 tabs. ISBN 90-6809-372-X, Euro 30,00

333 R SLUITER Mediterranean land cover change; Modelling and monitoring natural vegetation using GIS and remote sensing -- Utrecht 2005: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 147 pp, 39 figs, 23 tabs. ISBN 90-6809-373-8, Euro 17,00

334 M J HAGOORT The neighbourhood rules; Land-use interactions, urban dynamics, and cellular automata modelling -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 298 pp, 119 figs, 37 tabs. ISBN: 978-90-6809-374-2, Euro 25,00

335 M VISSERS Patterns of groundwater quality; In sandy aquiters under environmental pressure -- Utrecht 2005: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 144 pp, 46 figs, 7 tabs. ISBN: 978-90-6809-375-9, Euro 18,00

336 A B R WETERINGS Do firms benefit from spatial proximity? Testing the relation between spatial proximity and the performance of small software firms in the Netherlands -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 186 pp, 9 figs, 16 tabs. ISBN: 978-90-6809-376-6, Euro 22,00

337 I THONON Deposition of sediment and associated heavy metals on floodplains -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 176 pp, 56 figs, 19 tabs. ISBN: 978-90-6809-377-3, Euro 23,00

338 H S DANNER, J RENES, B TOUSSAINT, G P VAN DE VEN & F D ZEILER (Eds.) Polder pioneers; The influence of Dutch engineers on water management in Europe, 1600-2000 -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 177 pp, 61 figs, 1 tab. ISBN: 978-90-6809-378-0, Euro 14,50

339 A F KOEKOEK, J M VAN DER HAMMEN, T A VELEMA & M VERBEET (Eds.) Cities and globalisation; Exploring new connections – Utrecht 2006: Knag/VUGS/Faculteit Geowetenschappen Universiteit Utrecht/URU. 99 pp, 10 figs, 11 tabs. ISBN: 978-90-6809-379-7, Euro 10,00

340 G A VONK Improving planning support; The use of planning support systems for spatial planning -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 126 pp, 37 figs, 14 tabs. ISBN: 978-90-6809-381-0, Euro 16,00

341 M GEERTSEMA Hydrogeomorphic hazards in northern British Colombia -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 184 pp, 110 figs, 10 tabs. ISBN 978-90-6809-382-7, Euro 24,00

342 K K DEKKER Governance as glue; Urban governance and social cohesion in post-WWII neighbourhoods -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 158 pp, 4 figs, 23 tabs. ISBN 978-90-6809-383-4, Euro 18,00

343 G J J VAN DEN HOF PPS in de polder; De betekenis van publiekprivate samenwerking voor de borging van duurzame ruimtelijke kwaliteit op Vinex-locaties -- Utrecht 2006: Knag/Copernicus Institute. 248 pp, 10 figs, 18 tabs, 16 box, 26 pics. ISBN 978-90-6809-384-1, Euro 25,00

344 M VAN DEN BRINK & T METZE (Eds.) Words matter in policy and planning; Discourse theory and method in the social sciences -- Utrecht 2006: Knag/Nethur. 179 pp, 6 figs, 6 tabs. ISBN 978-90-6809-385-8, Euro 20,00

345 M J VAN DER MEER Older adults and their sociospatial integration in The Netherlands -- Utrecht/Amsterdam 2006: Knag/ Faculteit der Maatschappij- en Gedragswetenschappen Universiteit van Amsterdam. 168 pp, 16 figs, 26 tabs. ISBN 978-90-6809-386-5, Euro 23,00
346 E VAN BECKHOVEN Decline and regeneration; Policy responses to processes of change in post-WWII urban neighbourhoods -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 174 pp, 6 figs, 14 tabs. ISBN 978-90-6809-387-2, Euro 18,00
347 G VAN DER VEER Geochemical soil survey of the Netherlands. Atlas of major and trace elements in topsoil and parental material; assessment of natural and anthropogenic enrichment factors -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 245 pp + cd-rom, 56 figs, 50 tabs. ISBN 978-90-6809-388-9, Euro 30,00
348 G ASHWORTH, P GROOTE & T HAARTSEN Public places, public pasts -- Utrecht/Groningen 2006: Knag/Faculteit der Ruimtelijke Wetenschappen Rijksuniversiteit Groningen. ISBN 978-90-6809-389-6, Euro 25,00
349 L MEIJERING Making a place of their own; Rural intentional communities in Northwest Europe -- Utrecht/ Groningen 2006: Knag/Faculteit der Ruimtelijke Wetenschappen Rijksuniversiteit Groningen. ISBN 978-90-6809-390-2, Euro 25,00
350 Z FÖLDI Neighbourhood dynamics in Inner-Budapest; A realist approach -- Utrecht 2006: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 345 pp, 72 figs, 10 tabs, 34 pics. ISBN 978-90-6809-391-9, Euro 35,00
351 S AGTERBOSCH Empowering wind power; On social and institutional conditions affecting the performance of entrepreneurs in the wind power supply market in the Netherlands -- Utrecht 2006: Knag/Copernicus Institute. 246 pp, 36 figs, 8 tabs. ISBN 978-90-6809-392-6, Euro 27,50
352 C RINZIN On the middle path; The social basis for sustainable development in Bhutan -- Utrecht 2006: Knag/Copernicus Institute. 204 pp, 18 figs, 37 tabs, 5 box. ISBN 90-6809-393-2, Euro 22,50
353 M VAN WIJK Airports as cityports in the city-region; Spatial-economic and institutional positions and institutional learning in Randstad-Schiphol (AMS), Frankfurt Rhein-Main (FRA), Tokyo Haneda (HND) and Narita (NRT) -- Utrecht 2007: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 323 pp, 59 figs, 18 tabs. ISBN 978-90-6809-394-0, Euro 35,00
354 A C HELDERMAN Continuities in homeownership and residential relocations -- Utrecht/Amsterdam 2007: Knag/ Faculteit der Maatschappij- en Gedragswetenschappen Universiteit van Amsterdam. ISBN 978-90-6809-395-7, Euro 19,00
355 W BORREN Carbon exchange in Western Siberian watershed mires and implication for the greenhouse effect; A spatial temporal modeling approach -- Utrecht 2007: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 125 pp, 36 figs, 17 tabs. ISBN 978-90-6809-396-4, Euro 13,00
356 S O NEGRO Dynamics of technological innovation systems; The case of biomass energy -- Utrecht 2007: Knag/Copernicus Institute. 166 pp, 24 figs, 17 tabs. ISBN 978-90-6809-397-1, Euro 18,00
357 R NAHUIS The politics of innovation in public transport; Issues, settings and displacements -- Utrecht 2007: Knag/Copernicus Institute. 184 pp, 9 figs, 40 tabs, 4 box. ISBN 978-90-6809-398-8, Euro 20,00
358 M STRAATSMA Hydrodynamic roughnesses of floodplain vegetation; Airborne parameterization and field validation -- Utrecht 2007: Knag/Faculteit Geowetenschappen Universiteit Utrecht. 180 pp, 55 figs, 28 tabs. ISBN 978-90-6809-399-5, Euro 23,00
359 H KRUIZE On environmental equity; Exploring the distribution of environment quality among socio-economic categories in the Netherlands -- Utrecht 2007: Knag/Copernicus Institute. 219 pp, 76 figs, 25 tabs. ISBN 978-90-6809-401-5, Euro 25,00
360 T VAN DER VALK Technology dynamics, network dynamics and partnering; The case of Dutch dedicated life sciences firms -- Utrecht 2007: Knag/Copernicus Institute. 143 pp, 23 figs, 25 tabs. ISBN 978-90-6809-402-2, Euro 15,00

For a complete list of NGS titles please visit www.knag.nl. Publications of this series can be ordered from KNAG / NETHERLANDS GEOGRAPHICAL STUDIES, P.O. Box 80123, 3508 TC Utrecht, The Netherlands (E-mail info@knag.nl; Fax +31 30 253 5523). Prices include packing and postage by surface mail. Orders should be prepaid, with cheques made payable to "Netherlands Geographical Studies". Please ensure that all banking charges are prepaid. Alternatively, American Express, Eurocard, Access, MasterCard, BankAmericard and Visa credit cards are accepted (please specify card number, name as on card, and expiration date with your signed order).