FROM MIND TO MARKET AT UNIVERSITY

How Diversity in Knowledge Networks Makes a Difference

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How Diversity in Knowledge Networks Makes a Difference

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof. ir. K.C.A.M. Luyben,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op vrijdag 13 december 2013 om 10.00 uur

door

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Dit proefschrift is goedgekeurd door de promotor:
Prof. dr. M. van Geenhuizen

Samenstelling promotiecommissie:

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ISBN/EAN: 9789461862327

Printed in the Netherlands by Proefschriftmaken.nl || Uitgeverij BOXPress

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Introduction

1.1. Problem statement

Knowledge interaction between universities and the business community has received increasing attention in policy research in the last decade, and the entrepreneurial role of universities in industrial innovation, through the commercialization of their knowledge, is now well accepted in Europe and North America (Kim 2013; Van Looy 2011). The increased entrepreneurial activity on the part of universities, to gain financial revenues from their research on the one hand, and a growing need among companies to access externally generated knowledge, due to a strong competition in technology markets, and to share the risks and costs of research, on the other hand, have created different mechanisms of knowledge commercialization and the related interaction between university and industry, including partnerships in contract research/technology projects (Chesbrough 2003; Van Looy 2011; D'Este and Patel 2007; Bozeman et al. 2013), patenting and licensing of the knowledge from universities to convert research into commercially viable applications, and spin-off firms, which are considered a major knowledge commercialization mechanism (Mowery et al. 2001; Shane 2004; Djokovic and Souitaris 2008; Huggins and Johnston 2009; Kim 2013).

The performance of individual types of knowledge commercialization mechanisms, in particular direct university-industry relationships and research/technology projects, are addressed in many recent studies, because of questions regarding their effectiveness (Geuna and Muscio 2009; Bruneel et al. 2010; Kim 2013; Van Looy 2011; Bozeman et al. 2013; van Geenhuizen 2013), especially the modest performance levels of university spin-off firms in terms of employment, is something that many authors believe calls for further investigation (Dahlstrand 1997; Mustar et al. 2008; Gilsing et al. 2010).

To address this issue, this study looks at two major channels of this process, technology projects at university and university spin-off firms, with a particular focus on the underlying performance factors.

1.2. Theoretical perspectives

1.2.1. Introduction

In this section, the main theoretical views of this study, including the resource-based view, organizational learning theory and views on urban innovation, are discussed. The reason for selection of these theories are forwarded first.

Young and small university spin-off firms are in lack of valuable and scarce resources while they are subject to liability of newness which limits their growth

(Vohora et al. 2004; Lockett and Wright 2005; Mustar et al. 2006). They are facing shortage of specific resources, namely, financial capital and different types of knowledge (van Geenhuizen and Soetanto 2009). Survival and growth of spin-off firms are highly dependent on internal resources and external resources they access or gain through their networks (Mustar 1997; Pérez-Pérez and Sánchez 2003; Nicolaou and Birley 2003; Johansson et al. 2005; Walter et al. 2006). Because the main focus in understanding survival and growth of university spin-off firms is on firms' resources and capacities needed to gain missing resources, the resource-based view is adopted in this study as a broad framework view. Moreover, university spin-off firms are created based on new knowledge and/or technology created at universities and knowledge is a key resource for these firms and a source of competitive advantage. Since knowledge is a key resource (valuable, rare, inimitable and non-substitutable) for spin-off firms, organizational learning theory is also applied specifically to describe how spin-off firms use their internal capacities to acquire external knowledge and further assimilate the acquired knowledge to leverage already existing knowledge. Furthermore, the influence of knowledge acquisition through networks of firms and internal resources on firm growth are studied. Taking the fact that different types of urban locations provide spin-off firms with different external resources and that has impact on firm survival and growth (Audretsch and Feldman 1996; Capello 2006), urban innovation views are applied to describe the differences between growth of firms in different regions. Next, resource-based view, organizational learning theory and views on urban innovation are discussed in more detail for university spin-offs and university driven technology projects.

1.2.2. Resource-based view and organizational learning theory

Within a resource-based view on the performance of university-driven technology projects and university spin-off firms (Barney 1991; Barney and Clark 2007; Wernerfelt 1984, 1995), the main focus is on internal resources and capacities in the research teams of technology projects and founding teams of spin-off firms, and on the ability to get access to key external resources that are valuable, rare, inimitable and non-substitutable through networks (Gulati 1999; McEvily and Marcus 2005; Lavie 2006). Resources within a firm or research team can be defined as all tangible and intangible assets which, at a given time, are tied to the firm/research team, including organizational culture, accumulated knowledge, technical and managerial skills, investment capital, machinery and other resources.

Accumulated knowledge within the research team of technology projects and founding team of university spin-offs, mainly through the education and experience of team members, can be seen as a main source of competitive advantage influencing project and firm performance (Colombo and Grilli 2005, 2010). For example, it may affect the ability to recognize, acquire and assimilate new knowledge (Cohen and Levinthal 1990; Zahra and George 2002). Moreover, diversity in education and experience among team resources may influence the performance of university-driven technology projects and university spin-offs (Thornhill and Amit 2003; Beckman et al. 2007).

Organizational learning theory is also applied in this study, particularly when investigating research teams' connection with large firms and a firm's ability to acquire knowledge nationally and internationally. Organizational learning theory clarifies the behavior of research teams and spin-off firms in building knowledge relationships with different partners, with the aim of acquiring specialized knowledge and leveraging their ability to further sense, recognize and absorb new knowledge (Nooteboom et al. 2005; Zahra and George 2002). Although learning through external networks is particularly attractive if the network partners have a lot of new knowledge to offer, the partners should not be too different in terms of culture and routines (Nooteboom et al. 2005). A central concept is absorptive capacity, which refers to the ability of an organization to recognize, acquire, assimilate and exploit external knowledge (Cohen and Levinthal 1989; Zahra and George 2002). Gaining knowledge through networks is especially important for research teams at universities and the founding teams of university spin-offs, as both have limited internal resources, in particular in terms of team size and financial capital. Connecting with different local and global partners increases an organization's ability to gain access to different types of resources, which in turn increases the learning capacity of the teams involved (Powell et al. 1996; Clercq et al. 2012).

There is a broader development that provided a second reason to apply learning theory in understanding the characteristics of networks, and that is open innovation. The increasing competition in technology development and consumer markets has forced firms to reconsider their innovation strategy and start collaboration with other firms in more open ways (Chesbrough, 2003, Chesbrough et al. 2006; Laursen and Saulter 2006; Love et al., 2011). As a result, the innovation process has become more open, using external sources of knowledge, involving a wide range of partners, including customers, suppliers, universities and others, seems unavoidable for technology-based firms (Chesbrough 2003; Laursen and Salter 2006; Love et al. 2011). To adopt and benefit from open strategies is even more important to small spin-off firms, because they often face the dilemma of lack of resources and limited capabilities to build and maintain knowledge relationships.

1.2.3. Views on urban innovation

Urban innovation views are applied in this study to describe the differences in innovation activities in diverse urban locations. The type of urban location is an important factor that is thought to influence the innovative activities and growth of technology-based firms. Large cities in metropolitan areas are richer in external resources compared to smaller towns and rural areas (Audretsch and Feldman 1996; Capello 2006). The theory on agglomeration advantages states that firms in metropolitan areas are more likely to acquire resources in their local environment due to a higher level of knowledge spill-overs, high diversity in labor market of knowledge workers and greater access to other external resources (Leone and Struyk 1976; Gordon and McCann 2000; McCann 2001). Views on urban innovation describes the differences in performance of spin-off firms in contrasting urban environments, for which two cities were selected, Delft in the Netherlands, as an example of a city in a metropolitan area and Trondheim in Norway, as an example of a city in a remote area.

1.2.4. Knowledge commercialization and university-industry collaboration

Traditionally the university-industry interaction in commercializing knowledge was named knowledge transfer, refer to a linear model. In this linear model of knowledge transfer, education and research are carried at universities and their outputs in terms of (educated) people and research results flow into the economic sphere (Finne et al. 2011). University knowledge is transferred through different mechanisms, including networks among researchers and potential users, consultancy given by university experts to target clients, collaborative and contract research of universities in which clients play an important role in defining the research agenda, licensing of university’s intellectual property, usually to existing companies, the formation of new companies and teaching by university researchers. The knowledge continues to find its way to different clients and companies, government and society, and has an economic impact in the form of new jobs and/or new products and services. In recent knowledge transfer models, frequently named ‘knowledge commercialization’, the role of society, communities and user groups, and companies in posing innovative questions that are answered by universities, is becoming stronger, which means that society and companies are increasingly included in the innovation process from the start which accelerates the process by providing a better match with the needs of users and a shorter product or service design phase, using living labs and ‘testbeds’ (Dutilleul et al. 2010; Afonso et al. 2010; Livinglabs 2011; Leydesdorff 2012).

The models of collaboration of government (policy actors), university (traditional knowledge generation source) and industry are important in facilitating knowledge commercialization and university-industry collaboration (Triple Helix model) within a regional innovation system. Benefits for all three actors (or four actors in Quadruple Helix model, including user-groups) have only good chances to arise if these actors adopt some of each other’s activities and integrate to a certain extent, while they set agenda’s for future urban and regional development with shared aims and strategies (Etzkowitz 2008).

1.3. Elaboration of the research question

1.3.1. Introduction

In this section, problematic situations and knowledge gaps with regard to university knowledge commercialization are discussed, with a focus on the two modes of commercialization examined in this study, university-driven technology projects and spin-off firms. This leads to the main research question and its elaboration.

1.3.2. Problematic situations

Although university-industry interaction has existed for many years, in 2005, the initiative was taken in the Netherlands to formally establish knowledge commercialization as the third core activity (in addition to education and research) of higher educational institutes, including universities (Ministry OCW 2004). Despite various policy measures adopted in the Netherlands in more recent years to encourage universities in this effort, like the 'Valorisation Agreement' (2008), aimed at promoting collaboration between knowledge and research institutes, societal organizations, companies, investors and public authorities, and despite the activities of foundations and organisations like the Technology Foundation STW in granting subsidies to university technology projects and spin-off firms, this activity has not (yet) been sufficiently shaped as part of core activities of the university, and seems more dependent on individual initiatives rather than a university-wide strategy providing sufficient budgets (Geuna and Muscio 2009). To a large extent, the same situation exists in Norway, where a similar policy on the 'third mission' of universities was established, including the main strategy of achieving a knowledge-based economy through the promotion of stronger links between research, education and industry (OECD Reviews of Tertiary Education, 2009). Incubators were established in both countries (for instance Yes!Delft in Delft and Gloshaugen in Trondheim), and many spin-off firms took off and grew quickly after they started, but the seedbed for a sustained growth seems insufficient.

Many empirical studies indicate that the existing knowledge commercialization channels between universities and the business community do not operate as effectively as they could. In part, this has to do with different values and cultures between university and business environment (Bjerregaard 2010; Bruneel et al. 2010). Moreover, it has been argued that technology transfer offices in Europe lack the necessary capabilities (Geuna and Muscio 2009). A low effectiveness also holds true for spin-off firms when it comes to producing jobs (Mustar et al. 2008), which is why, as early as 2008, the OECD started to investigate regions and cities, with the aim of understanding what is missing in most university-business-government constellations.

While the pressure to move toward a knowledge-based economy is becoming stronger in Norway and the Netherlands, the effectiveness of the knowledge commercialization and interaction was called into question in both countries. In the OECD review of Higher Education in Regional Development (2010) for the region of Rotterdam/Delft, the communication and interaction of sub-national levels of government, the higher education institutions including Delft University of Technology and universities of applied science, and businesses were found to be not strong enough and the need to stimulate and improve them was considered vital. In the Nordic regions, knowledge institutions were found to play a non-significant direct role in innovative activities (Nordic Innovation Centre 2005), due to a mismatch between the content of university research programs and the composition of the regional economy. Accordingly, the design and implementation of more systematic ways of knowledge commercialization between universities and regional business were found to be of key importance.

1.3.3. Knowledge gaps

The university-driven technology projects as a channel of knowledge commercialization has attracted attention only in the past ten years (Caloghirou et al. 2003), and there have been only a few studies examining this area of research in recent years (Bekkers and Bodas Freitas 2011; Núñez-Sánchez et al. 2012; Breznitz and Feldman 2012). Bekkers and Bodas Freitas (2011), in their examination of university-industry collaborative projects in the Netherlands, look at organizational structures that affect the performance of university-industry collaborations, and Núñez-Sánchez et al. (2012) investigate the scientific and techno-economic effects of technology projects and their determinants. Breznitz and Feldman (2012) find that, through university projects, communities are used as laboratories to test new ideas, and universities are getting one step closer to reaching social and economic goals.

Although technology projects are considered an important way to commercialize university knowledge, relatively little is known of the market performance of such projects, including the underlying factors (Cohen et al. 2002; Caloghirou et al. 2003). According to organizational learning theory, the performance of research groups, as organizational units, is dependent on internal resources, namely, accumulated knowledge and experience within project teams, and external resources gained through the teams' networks, namely, by collaboration with large firms and other actors. There is, however, little empirical insight into these factors. Given the lack of research into the commercialization of university-driven technology projects, a research question is formulated to address the impact of the resources and capacities of research teams, including accumulated knowledge, on project performance.

Although it is believed that university spin-offs have a major direct and indirect economic impact (Di Gregorio and Shane 2003; Vincett 2010) through the diffusion of knowledge and the generation of new jobs (Pérez-Pérez and Sánchez 2003; Walter et al. 2006), there are clear indications that they exhibit a limited growth (Mustar et al. 2006; Wright et al. 2006; Wright et al. 2008; Geenhuizen and Soetanto 2009; Colombo et al. 2010). The reasons for this state of affairs are not fully understood, and the results of empirical research are sometimes contradictory, namely, the influence of diversity in founding teams on the growth of technology-based firms (Pelled 1996; Simsek 2009; Lichtenthaler 2012). Potential reasons for the stagnating growth are the limited financial and market-related resources or the composition of the starting teams. In addition, the lack of knowledge and experience, and the associated limited absorptive capacity may play a role as well.

However, firms can gain access to different valuable, rare and inimitable resources, including knowledge, through their networks. Moreover, the increasing need for specialized knowledge and specific partners, including customers and suppliers around the world (Teece 1992; Amin and Cohendet 2006), and the increasing global dispersion of technological competences, particularly including countries like China, Brazil, Korea and India (OECD, Technology and Industry Scoreboard 2012), require spin-off firms in Europe to establish knowledge collaboration at larger distances (Knight and Cavusgil 2004; Clercq et al. 2012), otherwise they may lose competitiveness and growth. In addition, the degree of openness to partners in a knowledge network with regard to amount and diversity of knowledge also may affect firm performance (Laursen and Salter 2006). Why some spin-off firms decide not to internationalize and to keep their networks relatively closed is, however, far from clear. Network openness has been studied with regard to large firms and, to a lesser extent, small and medium-sized companies (van de Vrande et al. 2009; Gassman et al. 2010; Hayter 2010), but it has not been studied for university spin-off firms. Accordingly, in this study, research questions are formulated to examine the knowledge network strategies of university spin-off firms with regard to internationalization and openness, using notions from resource-based view and learning theory including absorptive capacity.

With the aim of better institutionalizing the commercialization of university knowledge and underpinning policies for the knowledge-based economy, regional (local) policy-makers, both in the Netherlands and Norway, together with knowledge institutions, have a ‘mandate’ to look for a better alignment between the requirements of knowledge institutions and large and small businesses. This alignment is aimed to develop more effective programs that facilitate the commercialization of new university knowledge, while at the same time realizing there may be differences between remote areas and core metropolitan regions. Accordingly, in this study, questions are formulated that address the outcome of past and current supporting policies, in particular incubator programs in Delft and Trondheim, in terms of the growth of spin-off firms and the performance of technology projects that have been supported by some national programs since the mid-2000s, or even earlier.

1.3.4. Research questions

Given the problem statement discussed above, the aim of this study is to clarify the performance of two channels involved in the commercialization of knowledge from universities: technology projects and spin-off firms. The major research question is as follows:

How do characteristics of teams and external networks of organizations that are involved in university knowledge commercialization influence differences in the performance of these organizations?

Given the two channels of knowledge commercialization investigated in this study, a set of more detailed questions is formulated:

1. What is the performance of technology projects at university? What are the growth patterns of university spin-off firms over time?

Because there is virtually no literature on university-driven technology project performance in knowledge commercialization, a definition for technology project performance is developed in this study. Major dimensions in this definition are the actual outcome with regard to market introduction and the time frame involved (duration).

Firm growth can be captured by various indicators, including employment and sales growth, growth in relationships, fixed assets, etc. Small firms may grow through acquisitions rather than organic growth, or they may grow by expanding their networks and outsourcing part of their activities (Davidsson et al. 2006). In this study, growth is measured through employment and turnover growth along the lifetime of spin-off firms.

Taking two characteristics of firm external networks into account (more locally focused social networks and more formally oriented international networks); the following detailed questions are formulated:

2. What is the geographic pattern of knowledge relationships and degree of openness among spin-off firms? What drives spin-off firms to make their knowledge networks international and open?

To describe these network patterns, the concept of absorptive capacity, as a main driver in establishing knowledge networks and as the main element in team learning, is used (Cohen and Levinthal 1990; Zahra and George 2002). Absorptive capacity is conceived as encompassing two dimensions, namely, potential absorptive capacity, which makes firms eager and able to acquire and assimilate external knowledge, and realized absorptive capacity, which allows firms to leverage their knowledge by using the knowledge they have absorbed.

Openness in knowledge relationships is conceived as being characterised by two dimensions: capacity and diversity. Knowledge pool capacity, which refers to the 'size' of the external knowledge pool, is composed of breadth, the number of different types of knowledge received from partners, and depth, tie strength between the firm and its partners, which together constitute the knowledge pool that the firm actually accesses. Diversity, on the other hand, describes the heterogeneity of partners' social background. Moreover, the firms' international knowledge relationships are taken into account, as well as their learning and networking, as a compensation for local shortages in information and knowledge in remote cities (de Jong and Freel 2010; Isaksen and Onsager 2010).

In order to better describe the role of team capabilities and networks in achieving valuable, rare, inimitable and non-substitutable resources and in performance and growth, the following detailed question is put forward:

3. How do research team's internal resources and networks influence the technology project performance at university? And how do the spin-off team's resources, and openness and international reach of knowledge networks influence spin-off firm growth?

Taking the type of urban location as a characteristic of spin-off firms, the following detailed question is formulated regarding to the networks and performance of spin-off firms:

4. To what extent are firm performance and external network patterns different between cities with a different location?

1.4. Contribution of this study

This study provides critical reflection to the existing theory regarding knowledge commercialization, including university spin-off growth and technology project performance. This is concerned with (1) the growth of small technology-based firms in general, and (2) networking strategies, international orientation and openness of firms.

Firstly, the study confirms that resources-based view needs to include the positive influences of resources through networks compared to the firm's internal resources in terms of the characteristics of the founding team in the early growth, also revealed by other studies (Gulati et al. 2000; McEvily and Marcus 2005; Lavie 2006). This may also apply to technology project performance. In addition, the study complies with arguments of views on urban innovation in that small technology-based firms find it more difficult to grow in remote cities compared to core metropolitan cities, although a compensation for local deficiency of information and knowledge can take place by establishing networks over large distances, eventually abroad. It is found in this study that a location in a core metropolitan area reinforces spin-off firm growth in terms of employment, most probably due to a better access to additional networks and other supporting urban assets connected with the labor market (Gordon and McCann 2000; Capello 2006). In addition within the Netherlands, tends to be no difference in technology project performance between cities in core metropolitan region and those in South-east of the country. Responding to the shortage of resource-based views mentioned earlier, the influence of product markets is taken into account in this study. The results indicate that a higher level of competition in customer markets makes firms more open in terms of deeper search for knowledge. Also, the results indicate that market competition has a negative moderating impact on the influence of network diversity on firm growth. Moreover, market size has an influence on university-driven technology project performance.

In particular, the results of this study indicate that diversity in open innovation is important in networking for new knowledge (distances and partners) and increases firm growth. With regard to absorptive capacity and international networks, the study faces some difficulty in translating the concepts into measurable indicators but - given the indicators used - the study confirms a main role of absorptive capacity factors, namely, education level (PhD) and market and business-related training, representing potential absorptive capacity, and newness of innovation, representing realized absorptive capacity.

From a practical point of view, the findings of this study can be used to improve the support for technology projects initiated at university level and increase the early growth of university spin-off firms. This is particularly important, since there is a strong need to enhance the performance and tailor the support for knowledge commercialization at a technology project level and among spin-off firms (Mustar et al. 2008; Fini et al. 2009; van Looy 2011; ProInno Europe 2011; van Geenhuizen 2013). At a technology project level, the findings suggest an important role of collaborating with large firms on project performance that could be facilitated and supported to improve. The same applies to the negative influence of a relative lack of affinity with commercialization among project managers at university. In addition, the finding of a strong influence on growth from knowledge relationships with different types of local/regional and international partners can be used as a basis for designing more tailored support programs for spin-off firms in building such relationships. Moreover, our findings in contrast to some studies that show a positive influence of team diversity on firm performance, indicate that founding team diversity, in terms of education and experience, has an adverse effect on firm growth in the early stages of spin-offs, a situation that could be advised to be avoided at the start of spin-off firms.

1.5. Research approach and outline of the study

1.5.1. Research approach

In this study, a review of relevant literature on knowledge commercialization is the first step to identify the latest state of research in the field and to build the theoretical constructs of the study. As a result, several propositions related to the performance of university-driven technology projects and university spin-off firms are formulated. With regard to empirical data for testing the propositions and answering research questions, the study draws on two sets of existing data sets: interviews conducted with managers of technology projects and interviews with managers of spin-off firms. The latter database is a data set built at two points in time. Overall, data on technology projects and on spin-of firms has been checked and enriched by triangulation, using web-based information. The propositions are tested using data envelop analysis, focusing on efficiency, and using regression models and rough set analysis, both focusing on revealing the influences, the latter one more in a qualitative way.

1.5.2. Outline of the thesis

The study is organized in *nine* chapters, as illustrated in Figure 1.1 and it includes a compilation of four empirical papers, Chapter 4 to 7. The theory and concepts are elaborated and the propositions put forward in Chapter 2, and the methodology and operationalization of the concepts are discussed in Chapter 3. The performance of technology projects and the role of efficiency are studied in Chapter 4. International reach in knowledge networks by spin-off firms is investigated in Chapter 5, with special attention to absorptive capacity, while openness in networks in knowledge acquisition is investigated by focusing on the dimensions of knowledge pool and diversity in Chapter 6. Next, in Chapter 7, the focus of analysis is on the impact of diversity on spin-offs' growth through the firms' founding team and network, this is concerned with growth over the firms' lifetime. The study concludes with an overall interpretation of the results, a reflection on the research questions and propositions (Chapter 8), and with contribution, of the study, recommendations for future research and advice for the managers of incubators, universities and local/regional policy makers in Chapter 9.

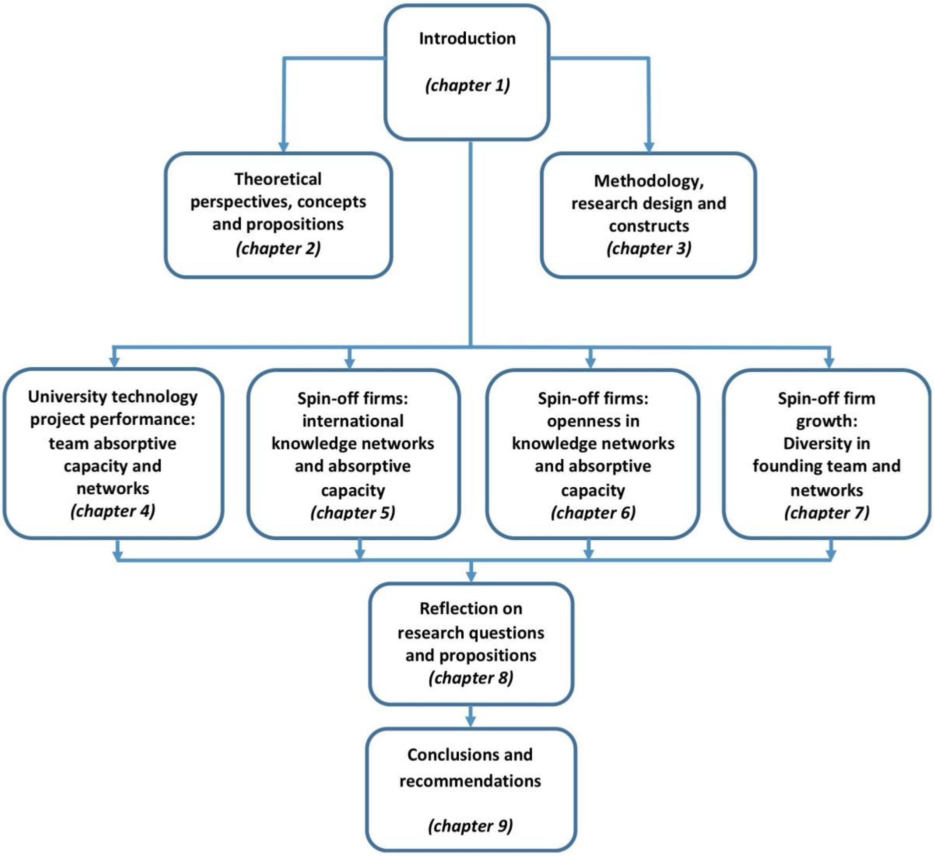

Figure 1.1. The outline of the chapters in this thesis

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Theoretical Perspectives, Concepts and Propositions

2.1. Introduction

In this chapter, the focus is on the main theories, perspectives and key concepts used in the study. The resource-based view and organizational learning theory are discussed and connected to better describe the performance of technology projects and spin-off firms, including their internal and external resources. Moreover, the relevant concepts of dynamic capabilities, absorptive capacity, open innovation and network openness, and diversity in teams and networks, are described and connected to the performance of projects and spin-off firms. This study also adopts a spatial perspective, which is why arguments from views on urban innovation are included in this chapter. The chapter begins by addressing a discussion of knowledge commercialization (section 2.2), followed by a discussion of resource-based theory and organizational learning theory, and the key concepts (section 2.3). The theoretical frameworks adopted in the individual chapters of this study (papers submitted to journals) are discussed next, along with a set of propositions (section 2.4). The chapter closes with a conclusion regarding the theoretical perspectives used in this study.

2.2. Knowledge commercialization through technology projects and university spin-off firms

Knowledge commercialization can be seen as a process in which value is added to new knowledge to transform it into a new or improved product, process or service in the market, in the Netherlands also named 'valorization' PricewaterhouseCoopers 2006; Valorisatieagenda 2008; van Geenhuizen 2013). It is a complex and interactive process between knowledge institutions, such as universities and firms, in which knowledge is made available to reach the market, while interactions between knowledge institutions and firms are crucial in all stages in reaching the market and realizing other forms of (societal) use (Valorisatieagenda 2008). In this study, the term knowledge commercialization is preferred over 'knowledge valorization', because it is the common term in the international literature, although 'knowledge valorization' is a slightly broader concept that better covers the technology projects discussed in Chapter 4, which in some cases have a societal rather than purely commercial application.

In recent years, knowledge commercialization has increasingly been receiving attention from research institutes and policy-makers within a European context, because, although large amounts of new knowledge are being produced, barriers between university, industry and other Triple/Quadruple Helix partners slow down the process of knowledge commercialization (e.g., Rasmussen et al. 2006; Etzkowitz 2008; Hussler et al. 2010). Recent studies have empirically examined the nature of inhibiting factors in university-industry relationships (e.g. Hall et al.

2001; Bjerregaard 2010; Bruneel et al. 2010) and found, among other things that differences in attitudes and matters relating to intellectual property (IP) play a crucial role.

The key channels of knowledge commercialization are patent application, licenses, research joint ventures and alliances, mobility of skilled human capital (graduates), research collaborations in projects and the formation of spin-off firms (Shane 2004; Huggins and Johnston 2009; Hussler et al. 2010). In this study, knowledge commercialization is investigated through two channels: university-driven technology projects that eventually include university-firm collaboration, and university spin-off firms.

Technology projects

The technology projects in this study are projects that are defined at universities and that successfully qualify for funding by Technology Foundation STW in the Netherlands. On their way to the market, these projects often start working together with a large firm or organization. University-industry collaboration is an increasing trend in Europe that started in the early 1980s (Charles and Howells 1992). However, so far, few studies have looked at knowledge commercialization at project level and little is known about the performance and results of such projects in terms of knowledge commercialization (Perkmann and Walsh 2007; Núñez-Sánchez et al. 2012). From a societal point of view, the results of technology projects in terms of market introduction and other societal uses, and the time needed to realize these results, are important. Note that this channel of commercialization cannot be fully distinguished from other channels, since a university technology project could turn into a collaborative university-industry research, and it subsequently could be the basis for the foundation of a spin-off firm.

University spin-off firms

University spin-off firms are a subcategory of new technology-based firms. They are independent firms whose technology is based on the exploitation of an invention or technological innovation, which implies substantial technological and market-related risks (Shearman and Burrell 1988). A broad definition embraces all new firms operating in ‘high technology sectors’ that are faced with a higher than average expenditure of R&D as a proportion of sales, or a sector that employs more ‘qualified scientists and engineers’ than other sectors (Butchart 1987).

Using the definition presented above, young university spin-off firms may be conceptualized as a subset of new technology-based firms (NTBFs) (Storey and Tether 1998) that introduce the knowledge developed at universities to the market. University spin-offs are, however, different from other NTBFs, because they emerge in a non-commercial environment and, in many cases, a research environment, in which uncertainty is controlled as much as possible in experiments, which means that the entrepreneurs are not well equipped to deal with uncertainties and that they are faced with major knowledge gaps concerning the market, marketing and management (e.g. Lockett et al. 2005; Wright et al. 2009; van Geenhuizen and Soetanto 2009).

University spin-offs have been studied extensively in the past years (for an overview, see Rothaermel et al. 2007; Djokovic and Souitaris 2008; Colombo and Grilli 2010), and several definitions have been proposed in literature. While some studies limit the category of university spin-offs to companies founded by faculty and staff members (Pérez-Pérez and Sanchez 2003), other studies broaden the concept to include firms that exploit the knowledge developed within universities, independent of who exploits that knowledge (Klofsten 2005; Rasmussen 2011). In this study, university spin-off firms are defined as firms established by academic entrepreneurs, including students, staff members and graduates, with the primary aim of bringing the academic knowledge to market (Pirnay et al. 2003). As a result, firms whose founders have no links to the university and who have merely bought patents from the university, are not included in the definition.

2.3. Theories on firm growth and organizational learning

2.3.1. Connecting resource-based view of firms, organizational learning theory and views on urban innovation

Young and small university spin-off firms are in lack of valuable and scarce resources, namely, financial capital and various types of knowledge which limit their growth (Vohora et al. 2004; Lockett and Wright 2005; Mustar et al. 2006; van Geenhuizen and Soetanto 2009). Moreover, spin-off firms are highly dependent on internal resources and external resources they gain through their networks in order to survive and grow (Pérez-Pérez and Sánchez 2003; Nicolaou and Birley 2003; Johansson et al. 2005; Walter et al. 2006). Since knowledge is a valuable, rare, inimitable and non-substitutable resource, spin-off firms use their internal capacities (absorptive capacity) to sense, acquire and assimilate external knowledge. In this study, resource-based view (RBV) in combination with learning theory is applied to analyse how firms use their internal capacities, namely, absorptive capacity to acquire knowledge through external networks. In the same line, internal resources within firms, namely, founding team diversity and external networks diversity are applied to investigate firm growth. Assuming that different types of urban location provide different sets of external resources, for example a richer set of labour market resources, which have an impact on spin-offs' firm survival and growth (Audretsch and Feldman 1996; Capello 2006), urban innovation views could increase insights into the differences in external resources provided by different cities and the impacts on firm external networks and firm growth. Figure 2.1 shows the theoretical views in describing firm growth, namely, resource based view, organizational learning theory and views on urban innovation (type of cities). The theories and views are connected through enabling mechanisms, capacities and resources. Two main types of key resources, namely, firm internal resources (including absorptive capacity) and external resources, through external knowledge networks and partly provided in the city are presented.

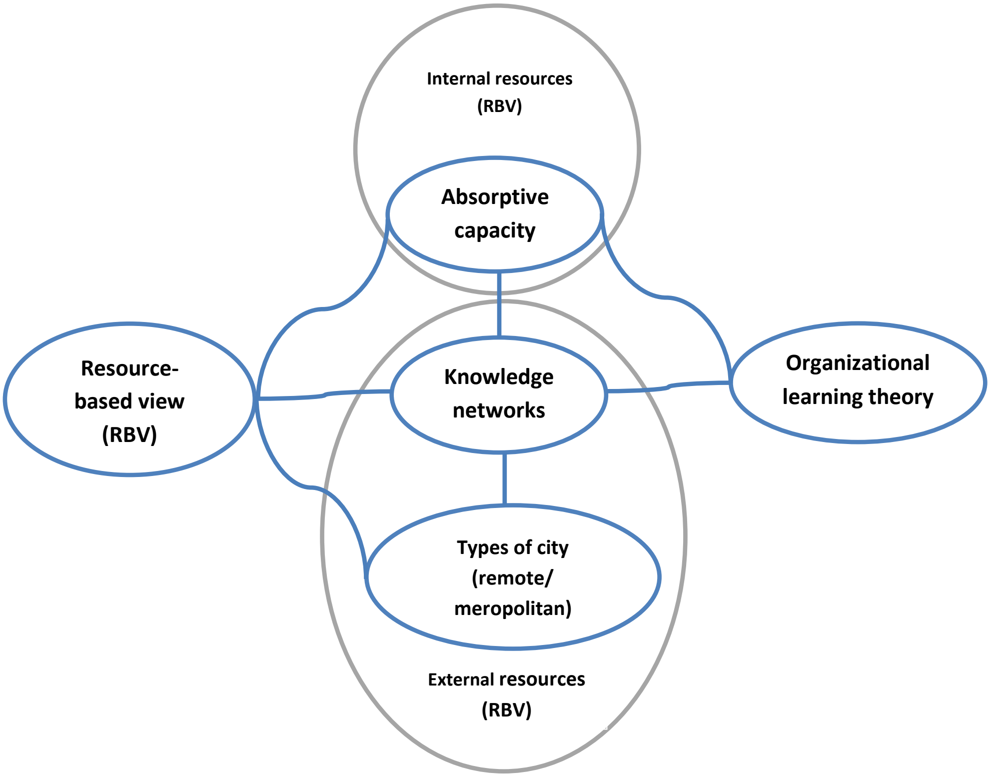

Figure 2.1. Theoretical views on firm growth

2.3.2. Firm growth

Growth can be seen as an increase in quantity or an improvement in quality. Firms grow in many different ways, internally and externally, and various indicators, for instance, employment and sales growth, growth in relationships and fixed assets, are used to capture firm growth. Small firms have more specific modes of growth, while they are more likely to grow through acquisitions than through organic growth (Lockett et al. 2009). Small spin-off firms may also grow by expanding their networks and outsourcing part of their activities (Davidsson et al. 2007).

Small firms may grow by expanding their networks and, in doing so, crossing their boundaries (Gulati et al. 2000; Schutjens and Stam 2003; McEvily and Marcus 2005). Firms expanding their network may have better opportunities to gain access to a wider set of resources, namely through a higher level of specialization of their customers and suppliers. With regard to international networks, there are generally speaking two models in the sense of starting business activities abroad, the incremental and 'born global' models. Small firms that internationalize incrementally, first establish a solid position in their domestic market. By contrast, 'born globals' initiate internationalization immediately or soon after they have been founded, for example by exporting to and building relationships in other countries (Madsen and Servais 1997; Andersson and Wictor 2003; Freeman et al. 2010).

2.3.3. Resource-based view of firms (RBV)

To examine the performance and growth of firms, many studies draw on Penrose's theory of growth of the firm (Penrose 1959), which states that the resources of a firm influence its growth and that growth is constrained when resources are inadequate. Later on, in 1980s, the resource-based view was elaborated and attention redirected towards the 'inside' of organizations (Hoskisson et al. 1999), in contrast to frameworks that focused on the firm's external environment, such as Porter's (1980) five forces. In these years, a series of important articles provided insight into how resources like organizational culture (Barney 1986), inimitable resources (Lippman and Rumelt 1982) and resources in general (Wernerfelt 1984) could contribute to organizational success. Barney (1991) further contributed to the argumentation that resources and capabilities are important for understanding the sources of competitiveness for firms and developed the core tenets of RBV. He presented a detailed definition of resources and elaborated the full set of key attributes (inimitable, rare, valuable and non-substitutable) that make a resource a potential source of competitive advantage. Kogut and Zander (1992) introduced the importance of knowledge as a resource to firms, and Grant (1997) articulated the knowledge-based view of the firm as a 'spin-off' of the RBV. Moreover, the overall construct of resources was divided into the two subcategories of resources and capabilities (Amit and Schoemaker 1993).

While the RBV focused on a firm's internal resources and capabilities, since the turn of the century, several scholars have drawn on network literature and highlighted the importance of external resources in the form of networks (Gulati 1999; Gulati et al. 2000; Hoang and Antoncic 2003; McEvily and Marcus 2005 Lavie 2006). Accordingly, the current study adopts the position that a firm's resources, either owned or accessed from external sources, are inputs that are converted into products or services for which revenue can be obtained, and that the attributes of resources indicated earlier contribute to a firm's competitiveness.

Overall, RBV offers significant insights into how competitive advantage can be achieved and sustained over time (Prahalad and Hamel 1990; Barney 1991). Firms that possess resources that are rare, valuable, inimitable and non-substitutable have sustained competitive advantages over other firms, because these resources enable them to create value in their operations that cannot be gained by competitors (Barney and Clark 2007).

There is also some criticism of the resource-based view. It has been argued that the role of specificities of product markets is underdeveloped in the resource-based view, that external factors relating to industry sector are neglected, and that firms could also be examined using Porter's industry structure analysis (Priem and Butler 2001). In addition, the resource-based view focuses on the characteristics of resources, paying less attention to the relationship between these resources and the way firms are organized (Wiklund and Shepherd 2003). Moreover, RBV was found to be self-verifying (Priem and Butler 2001). Barney defined a competitive advantage as a value-creating strategy that is based on resources that are, among other characteristics, valuable, while Priem and Butler (2001) perceived this reasoning as circular and therefore operationally invalid.

In this study, we attempt to move beyond this first by including the variables, namely, the level of market competition, market size, type of industry, and firm's networks, Second, by including firm absorptive capacity, partly measured through experience and the education of founders, firms' ability in combining and transforming tangible resources, namely, R&D expenditure, innovative products and patents is included. This ability of firm is difficult to imitate and results in a sustainable competitive advantage for firms (McEvily and Chakravarthy 2002). Third, In the design of the empirical study, factors with contradictory influences on firm performance are included to avoid self-verifying character of RBV.

Resource-based view and university spin-off firms

The following key perspectives and concepts related to the application of RBV on university spin-off growth, in particular internal and external resources including networks, including the social network approach, are discussed below.

In recent years, RBV has increasingly been applied to examine the growth of small high-technology firms, in particular university spin-offs (e.g. Reid and Garnsey 1997; Alvarez and Busenitz 2001). These firms, when they set out, own a set of resources, including the founders' specific knowledge and experience, and a set of dynamic capabilities (micro foundation of capabilities), that develop and change over time (Castanias and Helfat 1991; Teece 2007). Spin-off firms like firms in general continuously try to develop inimitable and scarce resources and capabilities, to respond to market and technology opportunities and threats, with the aim of gaining a competitive advantage over other firms.

Barney (1991) conceptualized a firm as a bundle of tangible and intangible resources, including a firm's management skills, its organizational processes and routines and the information and knowledge it controls, which can be used to select and implement strategies. The availability and diversification of resources (Harrison and Klein 2007) and the resources and capabilities within the founding or management team (Castanias and Helfat 1991) have been perceived as a source of competitive advantage and superior performance. Specific for spin-off firms, is in the course of their development cycle, there may be critical junctures because of a conflict between the existing (level and type of) resources, capabilities and social capital, and those required to reach the next development phase (Vohora et al. 2004). In many cases, young spin-offs fail because they have inadequate resources compared to what they need in that specific phase in their life line (Thornhill and Amit 2003; Vohora et al. 2004), which can be prevented if they increase their internal resources and capabilities by acquiring new staff and improving the quality of existing staff through training (Rickne 2006; Shepherd and Wiklund 2009), or by establishing relationships to gain access to external resources (Nicolaou and Birley 2003; Johansson et al. 2005). Moreover, they may enhance their resources through collaboration, merger and acquisition, through which they gain access to a wider pool of resources (Locket et al. 2009). However, spin-off firms may face a dilemma based on a gap between the resources that they need to access or gain through networks, and the limited resources (capabilities) they own to search for and establish the best networks.

One specific way to increase resources is through building social networks (Granovetter 1973; Gulati 1999; Gulati et al. 2000; Schutjens and Stam 2003; McEvily and Marcus 2005; Lambooy 2010). In this study, networks are perceived as structures made up of people and/or organizations (nodes) that are connected based on different interdependencies to share different resources, including financial capital, facilities, knowledge and other types of resources. Social networks are defined as social structures made up of persons or organizations connected through one or more specific type of interdependency, like friendship, kinship or a shared business goal (e.g., Uzzi 1996). Unlike market exchanges, social networks support exchange without using competitive pricing or legal contracting. The shared norms of the partners of social networks alone will ensure that the outcomes are fair, because these are socially embedded relationships, which sharply contrast with arm’s length relationships, which are established and modelled to avoid conflicts of interest between partners (e.g., Uzzi 1996).

Networks change in size and type over time, as social networks gradually develop into business type networks, including, for example contracts, as spin-off firms move from the early stage of development to later stages (Butler and Hansen 1991; Brüderl and Schüssler 1990). The networks may also change in terms of their openness, by including a higher diversity of partners, and in the strength and closeness of the relationships. Moreover, the geographical distribution may change over time, from local to regional and national, to international (Schutjens and Stam 2003), although, as indicated earlier in this chapter, there is a class of spin-offs that ‘go global’ from the start (Knight and Cavusgil 2004).

Diversity

In management studies, diversity is seen as a factor that makes a difference in firm growth, eventually related to internal resources, for instance, human capital in the form of the founding team (Thornhill and Amit 2003; Teece 2007; Beckman et al. 2007; Colombo and Grilli 2010) or resources a firm acquires externally. Although resource diversity may create synergy and enhance serendipity and, therefore, improves firm performance (Williams and O'Reilly 1998; Horwitz and Horwitz 2007), diversity, particularly within the firm (its starting team) may also harm growth. Gilsing et al. (2008) argue that, although cognitive heterogeneity among team members results in opportunities for new combinations of complementary resources, too much cognitive heterogeneity has negative impact on the shared understanding within a firm. A large degree of diversity may raise group fault lines in terms of education and experience, as a result of which people find it hard to understand each other, creating potential discord within the team, which has a negative impact on performance (Pelled 1996; Horwitz 2005; Colombo and Grilli 2010; Shirvastava and Tamvada 2011).

Existing literature also points to external networks as a source of accessing resource diversity. Most start-ups in the early years tend to rely on social networks, including partners with a similar background, like colleagues in incubators, family and friends, and often only start to rely on specialized partners from different backgrounds at a later stage (Larson and Starr 1992). These networks tend to compensate the lack of human and financial capital and other resources, as perceived in literature (Tether 2002; Pérez-Pérez and Sánchez 2003; Nicolaou and Birley 2003; Johansson et al. 2005; Walter et al. 2006; Drechsler and Natter 2012). One of the consistent empirical results in literature is that diversity in (social) firm networks positively influences firm performance (Powell et al. 1996; Soetanto 2009).

Diversity within a firm seems more important as it enables a firm to pursue explorative and exploitative activities simultaneously (Powell et al. 1996; Reagans and McEvily 2003; Simsek 2009). Diversity is associated with a firm's ability to exploit existing capabilities and opportunities as well as exploring new competences and strategies. The routines, processes and skills required for exploration are fundamentally different from those required for exploitation, while a certain degree of resource diversity could promote firm's ability in bringing a balance between explorative and exploitative activities, while increasing information and knowledge richness (Williams and O'Reilly 1998). Accordingly, a certain level of 'paradoxical' abilities that facilitate simultaneous exploration and exploitation, also known as ambidextrous capabilities, are seen as favorable for firms performance (March 1991; O'Reilly and Tushman 2004).

2.3.4. Organizational learning theory

Ways of learning

While the essence of network relationships in this study is based on acquiring and communicating knowledge and the influence of different attributes, like level of openness and international character, the study also uses organizational learning theory to elaborate the learning intention and capabilities of organizations in developing and benefiting from such relationships. Moreover, while the units of analysis in this study are university-driven technology projects and young university spin-offs, and their environment is characterized by uncertainty and turbulence (Utterback 1996; Tidd et al. 2009), the learning element is highly relevant, which is why other economic theories, such as game theory or (external) transaction cost theory, are not used. Another reason is that the main aim of research teams and spin-offs operating in knowledge networks is not directly profit-driven.

Organizational learning theory is part of organizational theory, which studies the ways organizations learn and adapt on the basis of learning. In the development of resource-based views of firms, Kogut and Zander (1992) emphasize the importance of knowledge as a scarce resource and as a source of competitive advantage for a firm. March (1991) describes organizational learning by two mechanisms. Firstly, the mutual learning between an organization and the individuals in it. Organizations store knowledge in their procedures, norms and rules and they accumulate such knowledge over time by learning from their members. At the same time, individuals in an organization are socialized to organizational beliefs. This mutual learning increases the convergence between organization and individuals beliefs. Secondly, organizational learning is the context of competition for primacy. Organizations often compete with each other to gain resources, in this case knowledge, to gain a competitive advantage, which is why organizations try to recognize and acquire knowledge through their networks and combine it with their internal knowledge to gain that competitive advantage.

In the remaining section, the following key concepts and perspectives on organizational learning in relation to the performance of spin-off firms and technology projects are discussed: paths of learning, absorptive capacity, explorative/exploitative learning, ambidexterity, open innovation and firm openness, and international knowledge relationships.

According to organizational learning theory, there are three main paths through which organizations learn (Argyris and Schon 1978; DiBella and Nevis 1998; Cohen and Levinthal 1990). First of all, organizations learn as a result of experience over time, for instance in the form of learning by doing. Secondly, organizations learn through passing different stages of development which could be the result of the evolution of the firm itself as an organization (life cycle), its product development (product life cycle), level of innovativeness and changes in markets (Handy 1993). Thus, the developmental perspective in learning puts an emphasis on the ability to adapt to a changing environment. The third path implies that no organizational learning occurs for a long time unless certain conditions are met, and learning takes place in the form of radical changes.

Absorptive capacity

The first two of the above-mentioned paths of learning require an important internal capability, known as absorptive capacity, which enables firms to recognize and acquire new knowledge, and subsequently assimilate that knowledge with the knowledge that already exists within the organization (Huber 1991; Cohen and Levinthal 1990; Zahra and George 2002). Conversely, if absorptive capacity is lacking, organizations are unable to recognize or acquire new external knowledge. In this situation, organizations are unable to learn from their partners or benefit from an open strategy unless they have already invested in their internal capabilities by educating their team and investing in R&D (Cohen and Levinthal 1990).

Developing certain levels of absorptive capacity within organizations or their teams is a source of competitive advantage and may describe many changes in strategy made in responding to the dynamics in the business environment, which in turn may describe firm positive performance and growth (March 1991; Teece 2007). With regard to absorptive capacity, Zahra and George (2002) distinguish two dimensions, potential absorptive capacity (PACAP) and realized absorptive capacity (RACAP). PACAP makes a firm eager to acquire new knowledge and allows it to acquire and assimilate external knowledge (Lubatkin and Lane 1998), while RACAP allows the firm to leverage its knowledge by using the knowledge it has absorbed. While a firm may acquire and assimilate knowledge, it may lack the ability to transform and exploit it for innovation and growth.

Explorative/exploitative learning

March (1991) describes the essence of exploitation as an extension of existing knowledge competencies, which has positive, proximate and predictable returns. In contrast, the essence of exploration is experimentation with new alternatives, which has uncertain, distant and often negative returns. Firms’ explorative and exploitative abilities can also be connected to a certain ability to first notice changes in their environment, and acquire and later on assimilate knowledge with existing knowledge. Both aspects of explorative and exploitative learning are seen as essential for organizations, particularly for firms in balancing the two in order to develop ambidexterity, which is a source of competitive advantage and growth (March 1991; O’Reilly and Tushman 2007).

Firm openness and open innovation

Through learning processes, organizations acquire knowledge internally or externally that they recognize as being potentially useful to the organization. However, the way of learning and innovation has changed dramatically in the past decades. Innovation is not merely dependent on the discovery of scientific knowledge or formal R&D activities within the organization; instead, it has become the result of various interactive processes by involving a wide range of parties, like suppliers, customers, competitors, universities, venture capitalists and government agencies (Chesbrough 2003; Laursen and Saulter 2006). This trend is popularized through the concept of open innovation, defined as the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for the external use of innovation, respectively (Chesbrough 2003). Co-creation is a way of simultaneous using inflow and outflow in close collaboration with a main partner (Enkel et al. 2009).

To be innovative and at the same time reduce the high level of costs and risks of developing knowledge in-house and speed up the development process, organizations adopt an open approach, even involving customer groups (Von Hippel 2005), and develop capabilities to recognize and acquire new external sources of knowledge (Mansury and Love 2008; Belussi et al. 2010). Organizations that are able to develop capabilities to utilize external sources of knowledge are more competitive and tend to perform better (Chesbrough 2003; Laursen and Saulter 2006; Mansury and Love 2008; Love et al. 2011; Fu 2012). Although open innovation is not a new phenomenon, it has received structural attention these days and has been adopted more often than before, due to the increased speed of technology development and global competition (Dahlander and Gann 2010; Huizingh 2011).

International knowledge relationships

Adopting an open strategy could connect organizations regardless of physical distances, as long as their cognitive proximity makes knowledge collaboration attractive (Boschma 2005; Torré 2008; Nooteboom et al. 2005). This is especially true for organizations using highly specialized knowledge and collaborating with highly specific customers, in particular firms with sophisticated products for a limited number of users/customers in the world (Jong and Freel 2010). Moreover, recent studies show the importance of knowledge collaboration on a global level (Kafouros and Buckley 2008; Clercq et al. 2012), because industrial competence is now widely dispersed all over the globe, whereas an increased specialization has limited the availability of specialized knowledge to only a few places in the world. As evidenced by the Science Technology and Industry Scoreboard of OECD (2011), the increased participation of countries like China, Korea, Brazil and India in international research collaboration becomes apparent. Thus, changes in the landscape of R&D and knowledge collaboration may urge young technology-based firms to cross larger distances to acquire competitive knowledge than in the past.

2.3.5. Views on urban innovation

On the basis of views on innovation and growth in cities, various arguments can be given on why and how innovation activities concentrate and perform better in some places and not in other ones. As already suggested by Marshall (1890) the concentration of firms in cities leads to the so-called ‘agglomeration advantages’, such as the availability of skilled and specialized labor force and the possibility to quickly exchange ideas and innovation. Accordingly, areas with high density offer better conditions for innovation and growth than low-density areas (Davidsson et al. 2010). In agglomeration theory, it is argued that innovation activities are more likely to be concentrated in large cities, because they provide a more encouraging environment, including (external) resources for the growth of young firms (Leone and Struyck 1976; Audretsch and Feldman 1996; Gordon and McCann 2000; Capello 2006). Along the same lines, theory suggests that innovative firms group together due to higher levels of knowledge spillovers and better learning possibilities, in part related to the availability of highly qualified and skilled workers, including the creative class with concomitant networks, open-mindedness and tolerance (Florida 2002).

With regard to cities as concentrations of economic activity, the question has long been whether the favorable influence on growth originates from a concentration of similar economic sectors (Marshall-Arrow-Romer model) or from different economic sectors. Jacobs (1969) argues that the most important source of knowledge spillovers is external to the industry in which the firm operates, thus pointing to diversity. Based on a large sample of American cities, it could indeed be confirmed that diversity matters in large cities (Glaeser 1992).

Based on a higher level of richness of resources in large cities, particularly knowledge diversity, firms in these areas are more likely to experience a higher level of growth and potentially also benefit more from diverse networks, however, some scholars suggest that proximity to networks is not necessary from benefiting from them (van Oort 2004).

2.4. Theoretical framework and related propositions

2.4.1. Research questions and propositions

Taking the main research question from the previous chapter as follows:

How do characteristics of teams and external networks of organizations that are involved in university knowledge commercialization influence differences in the performance of these organizations?

Different characteristics of teams and external networks are explored to describe the performance of technology projects at university and spin-off firms. Moreover, propositions are developed connecting with the main research question as follows:

- The performance of technology projects at university taking characteristics of research teams (absorptive capacity) and external networks of the teams into account, that are addressed in propositions 1.1 and 1.2.
- The performance of spin-off firms taking characteristics of founding teams (diversity) and external networks (diversity) into account, that are addressed in propositions 3.1(a,b) and 3.2.

Regarding to the following sub research questions:

What drives spin-off firms to make their knowledge networks international and open?

Two propositions are developed connecting with the above sub research question as follows:

- Establishing international knowledge networks at larger distances by spin-off firms taking characteristics of the founding team (absorptive capacity) into account is addressed in proposition 2.1.
- The level of openness in knowledge networks of spin-off firms taking characteristics of the founding team (absorptive capacity) into account is addressed in proposition 2.2.

Regarding to the following research question:

To what extent are firm performance and external network patterns different between cities with a different location?

- The type of cities (urban location) is taken as a characteristic of spin-off firms and its influence on firm performance is addressed in propositions 4.1 and its influence on network patterns is addressed in proposition 4.2.

The remaining sub research questions are about description of data, namely, geographical pattern of knowledge relationships, degree of openness, etc. for which there is no proposition but they are answered in respective chapters/papers.

2.4.2. Propositions

Chapter 4 deals with the performance of technology projects at universities in terms of commercialization. The theoretical framework is as follows. University-driven technology projects can be conceived as organizational units that depend on gaining access to resources for their performance. Although competition is not a primary driver, research teams enhance their competitiveness and strength partly through in-house resources, in the form of education and experience of the team (leader), and through their external networks, in the form of applying for research grants and working together with large firms. To be able to learn from external knowledge sources, research teams need to develop certain capabilities that enable them to recognize, acquire and assimilate new external knowledge (Lubatkin and Lane 1998; Zahra and George 2002). This means that a research team's absorptive capacity is an important factor that encompasses the ability to recognize and capture external knowledge resources (Cohen and Levinthal 1989). Knowledge is a key resource and absorptive capacity of research team is also vital to cross barriers in collaboration with business community and industry due to differences in attitudes, in terms of time lines, which in most firms are shorter than they are in university research, different intentions with regard to research results, namely disclosing them in journals versus protecting them by patents, different capabilities when it comes to handling patent applications, licensing, and different strategies for maximising benefits from patents strategies (e.g. Bjerregaard 2010; Bruneel et al. 2010). Thus, the path of collaboration of university teams with business firms in bringing inventions to market is covered with obstacles and barriers due to different values and priorities, objectives, and cultural and organizational differences between universities and businesses (Hall et al. 2001; Drejer and Jorgensen 2005).

With regard to the managers of university research teams, a sound ability in scientific research is not sufficient to bring the technology projects to market, they also need to be able to recognize external opportunities and identify applications of the technology, which increases the chance of bringing new technology to market. Moreover, the degree of accumulated knowledge within the research team, through the length of the time the manager has been active as a professor, reflects the experience of the manager in the subject matter and organizational aspects, that may increase team's absorptive capacity. Moreover, accumulated knowledge through other parallel/predecessor projects, might increase synergies and increase team's absorptive capacity. Other types of resources and capabilities within a research team that might increase team absorptive capacity, namely, availability of financial capital and ability of the team to leverage the existing knowledge and assimilate the newly acquired knowledge into existing team processes may affect learning possibilities of a research team and have influence on commercialization results of the technology projects.

Thus, different types of resources and capabilities within a research team, namely, the manager's experience and affinity with commercialization and resources gained externally through networks affect the research team's learning possibilities and commercialization opportunities. The circumstances outlined above influence the performance of technology projects in terms of commercialization and addressed in greater detail in Chapter 4, and are the basis of the following propositions.

1.1. The performance of university-driven technology projects in bringing new technology to market is positively influenced by higher levels of absorptive capacity.
1.2. The performance of university-driven technology projects in bringing new technology to market is positively influenced by networks with large firms.

According to the resource-based view, small technology-based firms, especially university spin-offs, compete to possess rare and hard to imitate resources and capabilities to gain a sustained competitive advantage over other firms (Barney and Clark 2007). Resources and capabilities in part already reside in a firm in the start-up phase and are mainly dependent on the characteristics of the founding team (Colombo and Grilli 2010). Accordingly, so-called prior related knowledge shapes the firm's absorptive capacity and allows it to recognize and acquire new knowledge, and to use it at later stages (Cohen and Levinthal 1990). Over time, investment in R&D or training will increase the absorptive capacity (Cohen and Levinthal 1990).

Knowledge is a scarce resource for spin-off firms, particularly knowledge regarding markets, marketing and customer requirements, making it an important source of competitive advantage (Grant 1997). Small spin-off firms tend to use external sources of knowledge to reduce the high costs and risks involved in producing knowledge internally (van de Vrande et al. 2009). Thus, spin-off firms build and reconfigure their internal and external competences to be able to recognize and acquire external knowledge sources and apply it in their innovation processes (Teece et al. 1997).

With regard to spatial reach in these relationships (internationalization), spin-offs tend to acquire new knowledge through their national and global networks, when it is not available locally or regionally (Torré 2008). Two types of knowledge are important in global networks. Firstly, knowledge of local markets abroad, dealing with particular customer requirements, regulations and industry standards, and secondly, knowledge regarding highly specialized technology that is available only in a few 'hot spots' in the world (Oviatt and McDougal 1994; Prashantham 2005).

The relationship between firm resources, including absorptive capacity, and 'acquiring global knowledge' is two-fold: firstly, firms may acquire unique knowledge abroad as a valuable resource and grow in competitiveness; and secondly, establishing knowledge relationships abroad requires the 'investment' of particular resources. The analysis in this study is limited to the role of resources related to absorptive capacity in establishing distant knowledge relationships, particularly international ones. Accordingly, pre-start education and experience, and participation in training may promote establishing long-distance international knowledge relationships (de Jong and Freel 2010; Clercq et al. 2012), which is discussed in Chapter 5. The role of absorptive capacity is the basis for the following proposition:

> *2.1. Establishing international knowledge networks across larger distances by spin-off firms is positively influenced by higher levels of a team's absorptive capacity.*

While the international nature is one attribute of knowledge relationships, openness in terms of the knowledge pool (breadth and depth) and in terms of partner diversity are other attributes. Openness can be seen as part of a firm's ability to identify opportunities and threads, and to maintain competitiveness in responding to the rapidly changing business environment (Teece 2007). Like with the international nature of knowledge relationships, a requirement for openness in networks is absorptive capacity. Accordingly, spin-off firms only build and maintain open networks if they own required resources, namely, financial resources, experience, education and time available to build open networks and master the risks involved with open relationships. Therefore, a set of absorptive capacity factors enabling internal learning processes, namely, education level and disciplinary and pre-start experience of the founding team and training received by the members of the firm, and a set of strategy factors that determine the nature of the learning processes involved, namely science-based versus non-science-based activity, innovation strategy and early ambition to grow are taken into account in this study. Openness is measured in two dimensions, i.e., openness capacity and openness diversity (Laursen and Salter 2006). Openness capacity, refers to the 'size' of the external knowledge pool, and is conceptualized as a two-dimensional variable composed of breadth and depth. Diversity, on the other hand, describes the heterogeneity of the partners' social (and geographical) background. The relationship between openness and absorptive capacity is addressed in Chapter 6.

> *2.2. The level of openness in knowledge networks of spin-off firms is positively influenced by higher levels of team's absorptive capacity.*

Spin-off firms are usually small with limited resources, especially in the earlier stages (Heirman and Clarysse 2004; Vohora et al. 2004; Lockett and Wright 2005; Mustar et al. 2006). In young spin-off firms, given the absence of hierarchal structures, the tasks of coordination and strategic planning are mainly performed by the founding team (Daily et al. 2002). According to the upper-echelon perspective, the quality of the founding team and management team are perceived to have a major impact on the performance of new start-ups (e.g. Fern et al. 2012).

In this vein, a large number of management studies in recent years have focused on team diversity (Ensley and Hmieleski 2005; Amason et al. 2006; Schjoedt and Kraus 2009; Fern et al. 2012), and takes diversity as a factor that makes a difference in growth, for instance with regard to diversity in human capital of a team in terms of age, gender, cultural background, education, industry experience, and business skills (Colombo and Grilli 2010; Beckman et al. 2007), however, the conclusion is ambiguous about the relationship between team diversity and growth.

By contrast, at an inter-firm level, there seems a consensus about a positive influence of network partners with diverse social backgrounds, integrating several spheres in society (Powell et al. 1996; Rodan and Galunic 2004), however, the risk of building too diverse networks has also been forwarded, given the limited firm resources and difficulties in managing diversity. Since networks are important channels for new technology firms to access resources that are missing (Pérez-Pérez and Sánchez 2003; Nicolaou and Birley 2003; Johansson et al. 2005), the focus of this study is on network diversity, by taking different social backgrounds into account, including the local-global dimension (Powell et al. 1996; Grandi and Grimaldi 2003; Reagans and McEvily 2003). The idea of diversity in the founding team and in the networks that contributes to growth of spin-off firms is elaborated in Chapter 7. The propositions are presented below.

3.1.a. Spin-off firms' performance since establishment is positively influenced by diversity in the founding team
3.1.b. Spin-off firms' performance since establishment is negatively influenced by diversity in the founding team
3.2. Spin-off firms' performance since establishment is positively influenced by diversity in the firm's network.

Urban innovation views indicate substantial differences in external resources that can be accessed in cities in large metropolitan areas in the core, compared to remote cities in Europe. Remote city in Europe is defined as a city at a large distances from big cities and from the core of Europe. The urban location is an important factor thought to influence the availability of external resources, with large cities in core metropolitan areas being better endowed, regarding diversity, compared to smaller cities in remote areas (Audretsch and Feldman 1996; Gordon and McCann 2000; Capello 2006). The influence of urban location on the performance of spin-off firms is discussed in Chapter 7.

A location in a remote city may encourage firms to enter into collaborations with more diverse partners. Following Feldman (1994) and de Jong and Freel (2010), it can be argued that distant/international collaboration is a response to a shortage of resources in the local/regional area. Thus, being located in a remote region in large countries makes it more likely that spin-offs bridge larger distances to acquire knowledge and internationalize than their counterparts in core metropolitan areas. The influence of urban location on establishing international knowledge relationships is discussed in Chapter 5, and the degree of openness of spin-off firms is addressed in Chapter 6. This argument leads to the following propositions:

4.1. An urban location in a metropolitan area has a positive influence on a spin-off performance.
4.2. An urban location in a remote area has a positive influence on a spin-off firm's level of openness and international knowledge relationships.

Table 2.1. Summary of propositions

Propositions	**Proposition number**	**Theory and concept**
Performance of university-driven technology projects is positively influenced by team's absorptive capacity	1.1.	RBV, Organizational learning and networks
Performance of university-driven technology projects is positively influenced by zteam's networks with large firms	1.2.	RBV, Organizational learning and networks
Establishing international knowledge relationships is positively influenced by the founding team's absorptive capacity	2.1.	RBV, organizational learning and ACAP
Firm openness is positively influenced by the founding team's absorptive capacity, an enabling and strategy factors	2.2.	RBV, organizational learning, ACAP
Growth of university spin offs is positively influenced by diversity in the founding team	3.1.a	RBV, organizational learning and diversity
Growth of university spin offs is negatively influenced by diversity in the founding team	3.1.b	RBV, organizational learning and diversity
Growth of university spin offs is positively influenced by diversity in firm networks	3.2.	RBV, organizational learning and diversity
Growth of university spin offs is positively influenced by being located in a metropolitan area	4.1.	RBV, urban innovation views
Firm international knowledge relationships and openness level is positively influenced by being located in a remote area	4.2.	RBV, urban innovation views

2.5. Conclusion

The perspectives of the resource-based view and organizational learning theory are adopted in this study to better describe how technology project teams and firms use their absorptive capacity and internal resources to benefit from external knowledge sources by developing open and international networks in an attempt to perform better and to grow. In addition, views on urban innovation are used to analyse the role of geographical location in establishing external networks by firms, and on firm growth. Linking these theories to the main concepts of absorptive capacity, network openness, founding team and network diversity, and urban location, several propositions are developed, to be tested in the following chapters. A summary of the propositions is presented in Table 2.1. An overview of the main theories and concepts that are used is presented in Table 2.2. The propositions forwarded in this chapter will be discussed in Chapter 8.

Table 2.2. The main theoretical views and concepts in study

Knowledge commercialization	**Theory**	**Main terms and concepts**	**Performance and growth**
University-driven technology projects	RBV, organizational learning theory and urban innovation views	Absorptive capacity, networks, urban location	University-driven technology project performance
University spin-offs	RBV, organizational learning theory and urban innovation views	Diversity in founding team, diversity in networks, Absorptive capacity, urban location	Spin-off firms' employment and turnover growth
		Absorptive capacity, urban location	Spin-off firms' openness in knowledge relationships

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Methodology, Research Design and Constructs

3.1. Introduction

In this chapter, the focus is on measuring the concepts discussed in Chapter 2. In addition, the research approach and methods used to analyze the knowledge networks, internationalization and openness, and the performance of technology projects and spin-off firms, are broadly discussed and the details are in the next chapters (Chapters 4 to 7). The databases used are described in section 3.2. The research approach and the methods and techniques that are applied in this study are briefly explained in section 3.3. The operationalization of concepts, using various sets of indicators in the individual chapters (Chapters 4 through 7) is summarized in section 3.4. Details and argumentation are presented in the individual chapters.

3.2. Databases

Two datasets are used in this study, firstly, a dataset on university technology projects, including broad and in-depth data on their performance, and secondly, a dataset on university spin-off firms and their performance. Both datasets were developed in previous studies.

Technology projects

In Chapter 4, university-driven technology projects are used as the unit of analysis, with the aim of measuring their performance and the factors underlying that performance. The analysis of the performance in terms of commercialization draws on two datasets. Firstly, a database of almost 370 projects, derived from Technology Foundation STW covering a number of years, representing different outcomes, including market introduction, continuation and failure, and secondly, a database derived from an in-depth study of 42 projects, representing the different outcomes and underlying factors. The projects started between 1995 and 1997 and between 2000 and 2002, respectively, due to the economic crisis of early 2000 (the end of the Internet bubble, see Kindleberger 2005), which could introduce a bias to an aggregate analysis covering the entire period. It is reasonable to assume that, in the early 2000s, firms were reluctant to become involved in commercialization. It is also reasonable to assume that there has been change in awareness regarding knowledge commercialization and the requirements for success in the two periods mentioned here: relatively low at the end of the 1990s and stronger since then, because of an increased policy attention to the commercialization of university knowledge (van Geenhuizen 2013).

The database of almost 370 projects represents the Netherlands, sub-divided between the core metropolitan area and the non-core South-East of the country. More than half of the sampled projects are executed at universities in the core metropolitan area of the northern part (Amsterdam) and southern part (Delft) of the Randstad region, while 31 per cent are executed in the non-core South-East area (Eindhoven and Maastricht); the remaining 17 per cent are based on collaborations between universities in different regions in the Netherlands. For both periods, failure of the commercialization is observed for 26 per cent of all projects, while bringing the product/process to market is observed for 22 per cent and 15 per cent, respectively, for older and younger projects. The second in-depth database (N=42) is derived from semi-structured interviews that were conducted in 2010 with 33 research managers at universities. This selected sample covers a limited number of technology segments, namely, medical life sciences and medical technology, and new materials and systems for sustainable technologies, including automotive. Commercialization is observed for 26 per cent of projects in this sample, with an average duration from the start of thinking about commercialization to the actual market introduction of the product/process (11 cases) of more than 7 years and a standard deviation of 4.31 years. More than half of the projects (23) in the in-depth sample resulted in a spin-off firm.

Spin-off firms

In Chapters 5 through 7, the unit of analysis is the university spin-off firm (USO). Data are used on 105 university spin-off firms in the Netherlands and in Norway. The selection of these data goes back to a study of the growth of university-related incubators in Europe, North America and some Asian countries (Soetanto and van Geenhuizen 2007). It was found that there are two factors that determine the growth of incubators, namely stakeholder involvement in establishing and managing the incubator, and the level of urbanization of the location (Soetanto 2009). Next, a framework was developed to select two incubators with a contrasting position with regard to these factors, on the basis of which the Norwegian University of Science and Technology (NTNU), Trondheim in Norway and Delft University of Technology (TU Delft) in Netherlands were selected (for more details, see Soetanto 2009). It should be noted that, since 2005, many developments were carried out in Delft and the single stakeholder involvement changed quickly to multiple stakeholder involvement, including the municipality, venture capitalists and large consultancy firms. Due to these new developments, the differences in stakeholder involvements were not taken into account in this study.

Delft University of Technology (TU Delft) is based in the city of Delft, a medium-sized city with 96,760 inhabitants (2010) in the province of South Holland (3.5 million inhabitants in 2010), which forms part of the Randstad metropolitan region in the Netherlands. The Randstad region is composed of several large cities, namely, Amsterdam, Rotterdam, the Hague and Utrecht, which are connected to each other. Two of the cities are located in the province of South Holland: the Hague, with a population of 488,553 inhabitants in 2010, is the home of the national government and many international organizations, while Rotterdam, with

593,049 inhabitants in 2010, is a center of seaport activity as a European main port, chemical industry, logistics and trading (Statistics Netherland 2010). The city of Delft is located at 10 km from the Hague and 12 km from Rotterdam, 54 km from Amsterdam and 53 km from Utrecht. Furthermore, Delft is located at 129 km from Brussels, Belgium, and at 367 km from Frankfurt, Germany. The major industry in South Holland is the commercial and service industry. In South Holland, the regional gross domestic product (RGDP) per capita was € 34,306 Euro in 2010 (Statistics Netherlands 2010). The Norwegian University of Science and Technology (NTNU) is located in the city of Trondheim in the center of Norway. It is the country's third largest city, with a population of 170,936 in 2010, and is the center of Trøndelag region (with 422,000 inhabitants in 2010). The city is dominated by NTNU, SINTEF and other technology-oriented institutions. In contrast to Delft, Trondheim is a single city far away from major urban centers, namely Oslo (389 km), Bergen (429 km), Stavanger (554 km). Trondheim is located at 609 km from Stockholm (Sweden) and at 871 km from Copenhagen (Denmark). The main industries in Trondheim are mining and agriculture, including farmed fish and processed wood, with oil and gas production being the fastest growing sector. The regional gross domestic product (RGDP) in the Trøndelag region was € 42,132 per capita in 2010 (Statistics Norway 2010).

The population of spin-offs from the two universities satisfied a number of conditions: they all dealt with the commercialization of knowledge created at the universities, survived to 2006 with an age not older than 10 years and had at least one type of support from their incubation organization/university. The data was collected using a semi-structured questionnaire in personal face-to-face interviews with the principal managers, in almost all cases a member of the founding team. To analyse the degree of internationalization in knowledge relationships and the level of openness in these relationships, as well as diversity in the founding team, cross-section data of 2006 was used. Firm growth, including employment and turnover, was measured at two points in time, 2006 and 2010, the latter through a short mail questionnaire, supplemented by website analysis. It needs to be noted that data collection on growth of spin-off firms, specially, for non-response cases, was easier for firms in Norway compared to firms in the Netherlands due to the availability of stronger search engines, namely, Purehelp which shows a more transparency in revealing annual performance results by firms in Norway.

In both countries, the sample of spin-offs contains manufacturing and service sectors. The manufacturing sector includes the manufacturing of machinery, chemicals, computer and electronic products, while the service sector mainly covers information and communication, and professional and technical activities (NACE). The new technologies involved include new material and nanotechnology, sensor technology, control systems, biotechnology and mechatronics. On average, the spin-off firms in the sample were 5 years old in 2006, in a range from 1 to 10 years, and they employ almost 7.5 full time equivalents (fte). Around 40 per cent of the sample is located in Trondheim and 60 per cent in Delft.

Studies like this one may suffer from selection bias as a result of excluding non-surviving firms. In this study, spin-offs that failed or were taken over and integrated into larger firms were excluded from the analysis in 2006. However, it was checked whether such firms are really different from the sample and it was determined that that is not the case (Soetanto 2009). Moreover, according to the estimations of managers of incubators, 80 percent of the spin-offs in Delft managed to survive the first ten years. Following the sample of 105 spin-off firms between 2006 and 2010, it is found that more than 90 per cent of the firms survived. For these three reasons, major selection bias in the results from non-survival can be excluded.

3.3. Research approach and methods of analysis.

This study is a compilation of four empirical chapters/papers (Chapter 4 through 7). In this study, each empirical chapter (Chapter 4 through 7) starts by reviewing relevant literature, to evaluate the mainstream theory and the current state of research on knowledge commercialization at the project level and the level of university spin-off firms, and on barriers to commercialization. Accordingly, literature on the resources-based view and organizational learning theory are summarized to describe how firm internal resources and capacities, namely, absorptive capacity enable a firm to establish knowledge relationships with external partners locally (openness) and internationally (internationalization) to get access to key external resources to gain a competitive advantage ahead of other firms. In the same line, firm internal resources and diversity among resources within a firm and resources gained through diverse network partners are applied to describe firm growth. Next, the main constructs (based on theory) are discussed and conceptual models are developed, and translated into measurable units (indicators). Various propositions are developed in Chapter 2 and discussed in Chapter 8 based on the results of Chapter 4 to 7.

Looking for revealing relationships between variables, regression analysis is used in this study. It needs to be noted that a regression analysis does not reveal causality between variables. Multivariate analysis is used in each chapter (from Chapter 5 to 7), for example, multiple regression analysis is applied to explore the extent of internationalization in knowledge relationships. Moreover, the level of openness of spin-off firms is modeled using multiple regression analysis. Multiple regression analysis is also applied to model the growth of spin-off firms since their establishment, in terms of employment and turnover growth, with an emphasis on diversity in the founding team and firm networks. In some parts of the modeling, there are good reasons to assume that the relationships are not linear but curvilinear in nature, namely, two directional influence of firm size on openness, leading to the application of some different regression models.

Moreover, in the exploration of technology projects in Chapter 4, rough-set analysis (RSA) is used to identify the factors underlying the differentiation in performance of these projects in terms of commercialization. This type of analysis, also called ‘qualitative correlation analysis’, matches with small samples and data that are sometimes fuzzy in nature (Pawlak 1991; for a new approach, see Klopotek et al. 2010). The technology projects in the study draw on subsidization with public money, which is why it is interesting to examine the efficiency of these projects. The efficiency of technology projects is measured using data envelop analysis (DEA), a non-parametric approach designed to measure the efficiency of decision-making units (in this case projects), using multiple inputs and outputs. This approach uses linear programming to build a piece-wise linear frontier and can be applied when there are multiple outputs without a meaningful aggregation and when the number of decision-making units is limited (Coelli et al. 2005; Thursby and Kemp 2002). The scores on DEA are included as an attribute variable in the rough-set model, to explore the performance of the projects with regard to commercialization.

3.4. Moving from concepts to variables

Reflecting on resource-based theory and learning theory (by including absorptive capacity), the main constructs are built and connected in each individual chapter (Chapters 4 to 7), whereas the unit of analysis is a university-driven technology project in Chapter 4 and a university spin-off firm in Chapter 5 to 7. In addition, the spatial dimension is included in all models, in terms of their geographical location (core-metropolitan versus non-core/remote).

In this section, the operationalization of these constructs is discussed in broad terms, allowing the reader to follow the details of measurement later in the empirical chapters (Chapter 4 to Chapter 7). As each of these chapters was meant as an article in a journal and reviewers asked for specific adaptations, somewhat different concepts are emphasized in the chapters. However, there is a certain overlap at the operationalization level. Details on how different concepts are operationalized in each chapter are discussed below.

Performance of technology projects

In Chapter 4, the unit of analysis is a university-driven technology project and the performance of technology projects is explored using rough-set analysis, a fuzzy based technique that produce decision rules in “IF condition(s) THEN decision” format. Several indicators representing *absorptive capacity* (as a resource) of research teams are used. Technology project performance is measured through a variable taking commercialization outcomes (ceased, partially continued, continued in research or pilot, and market introduction) and years of commercialization (duration) into account. The set of indicators representing the absorptive capacity of the project teams includes:

- Availability of financial capital, indicating whether the technology projects are facing limited resources (just STW funds) or more financing options are provided, namely from involvement of the business world or other public institutes. This capital is mostly spent on hiring researchers as PhDs for four years, thereby influencing the learning opportunities of research teams, which is why it is used as an indicator measuring absorptive capacity. This is measured as a categorical variable in two categories (limited financial resources only through STW funds versus more financial resources).
- Commercialization affinity of the manager indicates the level of affinity the project manager has with knowledge commercialization. It is measured using three categories (small, large, very large) as answered by the project managers.
- The manager being a star scientist or not, indicates the extent to which the manager is successful in both directions, science and commercialization, through honours, awards, large grants, patents and top-journal publications. It is measured in two categories (star scientist versus not a star scientist).
- Years of professorship of the manager, indicates the accumulation of knowledge and experience in terms of subject matter and organizational aspects regarding the search reteam. It is measured calculating the time between starting the professorship and the end of the project/observation (if a professor involved).
- Embedding of the project in parallel/predecessor projects, indicates the involvement of accumulated knowledge, synergies and scale advantages. This is measured in three categories (presence of predecessor or parallel projects, absence of both, and presence of both).
- Efficiency of technology projects is taken into account as an indicator representing realized absorptive capacity, since it is related to the ability of the team to leverage the existing knowledge and assimilate the newly acquired knowledge into existing team processes. It is measured using a data envelop analysis taking three input variables (duration of collaboration with large firms, financial investment and predecessor and/or parallel) and two output variables (outcomes in terms of commercialization and manager's satisfaction) into account.

In addition, the following factors are taken into account:

- Network capability of the team in view of collaboration with large firms, indicated by years of collaboration. It is measured taking the period between starting the collaboration and the end of the project/observation into account.
- Market-related influences, indicated by the size of the envisaged market (in three categories: small, medium and large) and the strength of market

regulations involved (in three categories: low, medium level and heavy) with new medicines and bio-implants, exemplifying heavy regulations.

The nature of the invention elaborated in the project is also thought to play a role in the commercialization of the knowledge, namely whether the invention is a radical one that faces resistance from existing structures or represents an incremental innovation (in two categories). The type of university involved may play a role as well, with technical universities mainly dealing with problem-oriented and engineering issues, while general universities, involved in chemistry, biology and physics, tend to focus more on fundamental research. It is measured in three categories (technical university, general university and collaboration between two types of universities).

Finally, the analysis takes regional differences into account, in three categories, distinguishing between universities located in the core metropolitan Randstad region, or in a non-core region, or in both types of regions, due to collaboration.

Internationalization in spin-off firms' networks

In Chapter 5, the unit of analysis is a spin-off firm and the spatial reach in international knowledge relationships is explored, whether a firm has such relationships, and on which continent. A set of indicators is used representing *absorptive capacity*, a distinction is made between potential and realized absorptive capacity (Lubatkin and Lane 1998; Zahra and George 2002):

- Potential absorptive capacity is measured indirectly, using indicators like a firm's R&D expenditure, size, experience, education level, multidisciplinary education and cross-cultural experience in the founding team and participation in market-related training.
- Realized absorptive capacity is 'captured' by level of newness of product/process and stage in product/process development, which indicate a firm's ability to leverage existing knowledge and assimilate the new acquired knowledge into existing processes/strategies.

Moreover, this part of the study controls for several variables, including firm age, firm size, type of industry and the market orientation of the firm. Finally, the study takes into account whether the firm is located in metropolitan area of Delft or non-metropolitan area of Trondheim. Spatial reach in international knowledge relationships (SRI) is an ordinal variable in three classes:

$$SRI\ (Not\ internationalized, Merely\ within\ Europe, Worldwide) \quad (3.1)$$

The general model of spatial reach in knowledge relationships, in the form of proportional odds model is presented in (3.4),

where there are K ordered categories of response with probabilities $\pi_1(x), \pi_2(x), \dots, \pi_n(x)$ when the covariates have the value x. Let SRI be the response which takes values in the range 1,…, K

with the probabilities given above and let $k_j(x)$ be the odds that $SRI \leq j$ given the covariates values x. Then the proportional odds model specifies that:

$$k_j(x) = k_j \exp(-\alpha^T x) \qquad (1\leq j < k) \qquad (3.2)$$

where α is a vector of unknown parameters. The ratio of corresponding odds is:

$$\frac{k_j(x_1)}{k_j(x_2)} = \exp\{\alpha^T(x_2 - x_1)\} \qquad (1\leq j < k) \qquad (3.3)$$

is independent of j and depends only on the difference between the covariates values $x_2 - x_1$. Since the odds for the event $SRI \leq j$ is the ratio $\frac{SRI_j(x)}{\{1-SRI_j(x)\}}$, where $SRI_j(x) = \pi_1(x) + \cdots + \pi_j(x)$, the proportional odds model is:

$$\log[\frac{SRI_j(x)}{\{1-SRI_j(x)\}}] = \theta_j - \alpha^T x \qquad (1\leq j < k) \qquad (3.4)$$

with $\theta_j = \log k_j$

and the covariates in model (3.4) are as follows:
R&DExp is R&D expenditure measured as the percentage of average turnover over spent on R&D over the past three years
FouExp is founder experience measured as an average number of working years of three first founders
FouEduLev is founder education level measured as the number of PhDs in founding team
FouTSize is founding team size measured as number of employees as fte at foundation
MultiEdu is multidisciplinary education of founders measured in two categories: single discipline versus multiple disciplines
PartTrain is participation in market related training measured in two categories: (Yes/No)
CulExp is cross-cultural experience in the founding team is a variable in two categories (Yes/No) taking the country of birth of founders and their parents into account
Newness is newness of product/process measured as a variable in three categories: low, medium and high level
ProdDev is a stage in product/process development measured as a variable in two categories: pilot/testing versus introduced to market
ULoc is urban location as a variable in two categories: Trondheim versus Delft
MarktOr is market orientation measured as a variable in two categories: regional/national versus international
Size is firm size measured as number of employees as fte in 2006
Industry is a variable in two categories: science-based versus market-based

Openness in spin-off firms' networks

In Chapter 6, the unit of analysis is a spin-off firm and the openness in knowledge relationships is explored using two dimensions of external knowledge: capacity and diversity (Laursen and Salter 2006; Barge-Gil 2010).

- External knowledge capacity as the 'size' of the knowledge pool, is indicated by using breadth, which refers to the number of different types of knowledge received from partners and depth, which indicates tie strength between the firm and its partners. Diversity of external knowledge is captured by the partners' social background, including their geographical orientation. The details of calculations regarding to openness capacity and diversity can be found in Chapter 6.

Two sets of variables - enabling factors and strategy factors - are used to explore openness capacity and diversity:

- Dynamic capabilities are captured indirectly, through firm characteristics that enable internal learning processes, firm age and firm size, the size of the founding team, education level and education discipline and pre-start experience of the founding team and participation in market-related training.
- A set of strategy factors determining the nature and direction of the learning processes and the need for openness is included: innovation activity, having adopted a certain degree of prospector strategy and firm early ambition to grow in size and network.

In the analysis of openness of knowledge networks, two factors are included as control variables: the level of market competition, and the urban location. The way openness is measured is explained in Chapter 6. The general model investigating openness including the control variables is as follows:

$$Openness = \alpha_0 + \alpha_1\, Size + \alpha_2\, FouTSize + \alpha_3\, ExpBre + \alpha_4\, ExpDep + \alpha_5\, MultiEdu + \alpha_6\, PartTrain + \alpha_7\, FouEduLev + \alpha_8\, InnoAct + \alpha_9\, EarlStra + \alpha_{10}\, Prospect + \alpha_{11}\, ULoc + \alpha_{12}\, MarktCom + \varepsilon \quad (3.5)$$

Where,

Openness is measured in two dimensions: *Openness capacity* is indicated by using breadth and depth. *Openness diversity* measured through partners' social background, and their geographical orientation. For details of calculations, see Chapter 6.
Size is firm size measured as number of employees as fte in 2006
FouTSize is founding team size measured as number of employees as fte at foundation
ExpBre is experience breadth measured as sum of years of founder's experience in research/management and other areas
ExpDep is experience depth measured as a sum of years of founder's pre-start working experience in similar sectors
MultiEdu is multidisciplinary education of founders measured in two categories: single discipline versus multiple disciplines
PartTrain is participation in market related training measured in two categories: (Yes/No)
FouEduLev is founder education level measured as the number of PhDs in founding team
InnoAct is innovation activity measured in two categories: science-based versus non-science-based activity
EarlStra is early growth strategy measured in three categories: large firm with international orientation, small with international orientation and small firm with local orientation
Prospect is prospector strategy measured as a variable includes level of innovation, patenting strategy and the amount of R&D expenditure
ULoc is urban location as a variable in two categories: Trondheim versus Delft
MarktCom is market competition measured as a variable in two categories: many competitors versus few competitors

Performance of spin-off firms

In Chapter 7, the unit of analysis is a spin-off firm and the performance of firms is examined in terms of employment and turnover growth since the foundation, using two sets of indicators, representing diversity in the founding team and diversity in the networks:

- Diversity in founding teams is captured by measuring diversity in the education and experience of founders using Blau index. It is calculated as $(1 - \sum p_i^2)$ where p is the proportion of team members in a category and i is the number of different categories in a team.
- Diversity in firm networks is captured through the international networks and social networks of the firms taking the social/economic background of partners and their spatial orientation into account. This is described in details in Chapter 7.

The study controls for several variables: early growth strategy, market competition level, year of firm foundation, founding team education level and firm size. Firm employment growth since foundation ($EGrowth$) operationalized as follows:

$$EGrowth = (Size\ 2010 - Size\ at\ start)\ /\ (Age\ 2010) \qquad (3.6)$$

And the general model investigating employment growth is:

$$EGrowth = \alpha_0 + \alpha_1\, ExpDiv + \alpha_2\, EduDiv + \alpha_3\, IntNet + \alpha_4\, SocNet + \alpha_5\, EarlStra + \alpha_6\, YFou + \alpha_7\, FouEduLev + \alpha_8\, FouTSize + \alpha_9\, ULoc + \alpha_{10}\, MarktCom + \varepsilon \qquad (3.7)$$

Turnover growth since foundation ($TGrowth$) is an ordinal variable in five classes:

$$TGrowth\ (No\ growth, Low\ growth, Medium\ growth, High\ growth, Very\ high\ growth) \qquad (3.8)$$

And the general model investigating turnover growth is similar to what explained in (3.2) to (3.4) and is presented in (3.9):

with K ordered categories of response when the covariates have the value x. $TGrowth$ is the response which takes values in the range 1,…, K, where α is a vector of unknown parameters.

The odds for the event $TGrowth \leq j$ is the ratio $\frac{TGrowth_j(x)}{\{1-TGrowth_j(x)\}}$, and the proportional odds model is: $\log[\frac{TGrowth_j(x)}{\{1-TGrowth_j(x)\}}] = \theta_j - \alpha^T x \qquad (1 \leq j < k)$ (3.9)
with $\theta_j = \log k_j$.

and the covariates in models (3.7) and (3.9) are as follows:
ExpDiv is experience diversity of founders measured as a continuous variable derived from experience of founders, i.e. technical, managerial and others, calculated using Blau index
EduDiv is education diversity of founders measured as a continuous variable derived from different education disciplines, calculated using Blau index
IntNet is international knowledge network measured as a variable in two categories: established knowledge relationships abroad versus no such relationships
SocNet is social network diversity measured as a continuous variable taking the socio-economic background of partners and their spatial orientation into account, see Chapter 7
EarlStra is early growth strategy measured as a variable in three categories: large firm with international orientation, small with international orientation and small firm with local orientation

YFou is year of foundation measured as a continuous variable shows the year in which firm founded
FouEduLev is founder education level measured as the number of PhDs in founding team
FouTSize is founding team size measured as number of employees as fte at foundation
ULoc is urban location measured as a variable in two categories: Trondheim versus Delft
MarktCom is market competition measured as a variable in two categories: many competitors versus few competitors

3.5. Conclusion

In this chapter, we discussed the data used in measuring university-driven technology projects and university spin-off firms. Furthermore, the research approach was explained, in addition to the operationalization of concepts and the use of indicators in the measurement. As mentioned earlier, this chapter contains a relatively broad outline of the indicators and the way they are measured. The following chapters present a more detailed discussion. Next, Chapter 4 deals with technology projects, the extent to which they are brought to market and which factors influence this process.

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Bringing Technology Projects to Market: The Role of Project Team Absorptive Capacity*

Abstract

To date, the commercialization of university-driven technology projects, particular their performance, has attracted little attention in empirical literature, despite the fact that commercialization of knowledge is increasingly seen as the third task of universities. Consequently, the purpose of this chapter is to characterize the level of commercialization and the factors underlying the differentiation in project performance in this commercialization. In an explorative approach, this study uses data envelop analysis, combined with rough-set analysis, to examine the efficiency of university-driven technology projects in terms of their commercialization results, as well as the factors influencing the overall performance in commercialization. The results of this study indicate that the major factors influencing overall performance tend to be the years of collaboration with large firms and the efficiency of the projects, although the affinity with commercialization among project managers at university also plays a role, since it helps to shape the absorptive capacity of the project team in recognizing new market opportunities. To be more precise, the best overall results in terms of commercialization (market introduction in a relatively short time) are realized with a longer period of collaboration with large firms and a medium level of efficiency.

4.1. Introduction

Scholars agree that developments in the 1990s and 2000s, both in the US and Europe, including measures that regulate intellectual property rights (Mowery et al. 2004) have led to a more direct involvement of universities in the business community (Geuna and Muscio 2009; van Looy et al. 2011). Universities are not only seen as educational institutes and the creators of new knowledge, but also as being involved in contract-research commissioned by the business sector, in collaborative technology projects with business partners, in the creation of spin-off firms, etc. (van Geenhuizen and Nijkamp 2006; Huggins and Johnston 2009; Shane 2004).

* An earlier version of the work, M. Taheri as the first author, co-authored by Marina van Geenhuizen as a supervisor, has been presented at the High Technology Small Firms Conference in Manchester, May 2013. A later version has been submitted to Studies in Higher Education. Propositions 1.1 and 1.2 concerning technology projects as posed in Chapter 2 are not directly investigated in this chapter but in the reflection on propositions in Chapter 8. This study was a part of the NICIS study on knowledge valorization named ‘knowledge valorization and local/regional benefits’ (2008).

In Europe, this new role of universities started to grow in the early 1980s (Charles and Howells 1992) and has now fully entered the research policy of modern universities (e.g., Hussler et al. 2010; Rasmussen and Borch 2010), and these days, knowledge commercialization is officially considered a task of universities (Etzkowitz 2008). For example, in the Netherlands, the commercialization of knowledge was officially recognized as the third task of universities, in addition to education and research, in 2008, and this has been substantiated in the 'Valorisationprogram' in 2010 (Innovation Platform 2009; Agentschap NL 2010).

Today, the issue is not to establish knowledge interaction or transfer, but to improve the efficiency and effectiveness of the existing interaction between universities and the business community, in a time when pressure from the knowledge economy and society is becoming stronger. University spin-off firms in Europe often display low levels of efficiency, with most of them staying very small (Mustar et al. 2008), while technology transfer offices suffer from a lack of capabilities (Geuna and Muscio 2009), and direct university-business links are less productive, due to barriers following from differences in culture and attitudes (Bruneel et al. 2010).

Knowledge commercialization, as conceived in this paper, encompasses interaction between the university, businesses and society. It is the "process of creation of value from knowledge, by adapting it and/or making it available for economic and/or societal use, and transform it into competing products, services, processes and new economic activity" (Innovation Platform 2009, page 8). Knowledge commercialization includes chains of processes that start with initial thoughts about market introduction, eventually together with a firm, and about steps that need to be taken to realize that market introduction through various channels (Bekkers and Bodas Freitas 2008).

Among the many channels used to commercialize knowledge, technology projects, eventually through collaboration with firms, have attracted little attention in existing literature (D'Este and Patel 2007; Gilsing et al. 2011), while the success in such collaborations is called into question by some scholars (Cohen et al. 2002; Caloghirou et al. 2003). Exceptions to the small attention are the study by Breznitz and Feldman (2012) on different types of engagement of universities in projects with local communities in the US, to evaluate the contribution of universities to economic development (a qualitative study), and the study by Bekkers and Bodas Freitas (2011) on university-industry collaborative projects in the Netherlands, in which organizational structures that affect the performance of university-industry collaborations are explored. In addition, Fontana et al. (2006) emphasize the importance of searching, screening and signaling in university-industry technology projects, based on a sample of small innovative firms in seven EU countries, while Núñez-Sánchez et al. (2012), based on project-level relationships for the Spanish case, investigate the scientific and techno-economic impacts of technology projects and their determinants. Most of these studies suggest that there is a lack of knowledge regarding the way technology projects develop in reaching the market and regarding the factors that determine the outcomes, one of which is efficiency (Perkmann and Walsh 2007; Núñez-Sánchez et al. 2012).

While the commercialization of university knowledge is receiving more attention today, there are no studies that examine the efficiency of the processes involved or that adopt an input and output approach to the subject. It should be noted that an input and output approach is common practice in policy areas, namely higher education (Jones 2006) including efficiency of universities (Thursby and Kemp 2002) and academic research (Cherchye and Abeele 2005; Lee 2011). As such, since virtually nothing is known about the background of the performance and efficiency of technology projects in terms of commercialization, the aim of this chapter is to explore the factors underlying the performance of technology projects in terms of reaching the market. In doing so, we address the knowledge gaps indicated earlier by examining the following questions: To what extent do technology-based projects at universities manage to reach the market and/or lead to other commercialization outputs, and how can project efficiency in this development be characterized? Which factors contribute to the overall performance of university-driven technology projects in terms of their commercialization?

Two databases are used, one of which the annual publications of Technology Foundation STW (several years) regarding the broad results of a large number of technology projects, while the other is based on in-depth interviews with the managers of technology-based projects at the university (van Geenhuizen 2013). The Netherlands serves as an example for a specific group of European Union countries that face the so-called ‘knowledge paradox’ of a high R&D input and a low innovation output (or growth), a group that includes Norway, Sweden, Austria and parts of United Kingdom (Audretsch and Keilbach 2007; Bitard et al. 2008; ProInno Europe 2012).

This chapter is structured as follows. Model building, including the choice of input and output variables in the efficiency analysis (Data Envelop Analysis) and the choice of factors influencing the overall performance in commercialization (Rough Set Analysis), takes place in Section 4.2. Section 4.3 deals with methodology and measurement issues, including the measurement of project efficiency. This is followed by a descriptive analysis of the outcomes regarding efficiency and overall commercialization, based on the trend study and the in-depth study, in Section 4.4. In Section 4.5, the results of the overall performance model are presented. We conclude with implications of the results and suggestions for future research in 4.6.

4.2. Knowledge commercialization processes

4.2.1. Resources and projects' efficiency

Adopting a resource-based view (Barney and Clark 2007), university-driven technology projects can be conceived as organizational units that depend on their internal resources and resources through their networks for their performance in commercialization. Although competition is not a primary driver, research teams of technology projects enhance their competitiveness and strength partly through in-house resources, in the form of education and experience of the team (leader), and through their external networks, by applying for research grants and working together with large firms. Knowledge is a key resource and learning is crucial for being able to cross barriers with the business world in the process of university knowledge commercialization. Based on organizational learning theory, research teams can be perceived to be in need of certain capabilities that enable them to recognize, acquire and assimilate new external knowledge, named absorptive capacity (Zahra and George 2002; Lubatkin and Lane 1998). Moreover, research teams learn through two main processes: (1) learning within teams, such as learning by doing, and (2) learning from external sources and inter-organizational learning.

Connecting with external sources, especially large firms, is considered important by providing research groups with an access to a wider pool of valuable and rare resources, facilitating and increasing learning opportunities of research teams, enhancing their chances in raising additional funding, namely, based on their improving reputation and enabling marketing the project results in an efficient way (D'Este and Perkmann 2011; Lee and Bozeman 2005; Bozeman et al. 2013). This is the more important for small university research groups with limited resources. However, in university-industry collaborations, there are many potential obstacles, caused by differences in attitudes and intellectual property (IP) strategies (e.g. Bjerregaard 2010; Bruneel et al. 2010). These different attitudes are related to time lines, which in most firms are shorter than they are in university research, while firms need to adapt quickly to changing external circumstances, even ending collaboration when a new technology enters the firms following a merger/acquisition, or when reorganizations dictate the closure of the firms' R&D department. Universities, by contrast, remain quite stable in their choices. In addition, researchers are keen to disclose information in journals as quickly as possible, while firms often prefer to keep new knowledge under wraps (Westness and Gjelsvik 2010; van Geenhuizen 2013). Obstacles between universities and firms also involve their different approach to patent applications and licensing, and in the way they try to benefit optimally from existing patents. Thus, while there are many benefits to this type of collaboration, there are a lot of obstacles to be overcome, pointing to the importance of the duration of the collaboration.

The accumulated knowledge and experience of research teams is considered as a valuable, inimitable and non-substitutable resource enables research teams to learn by sense new knowledge and to acquire and assimilate it and has an influence on the outcome of technology projects. In studies measuring research performance, for example Lee (2011), full-time equivalent staff in research is used as an input factor. The accumulated knowledge within the research team is included in the model in this study mainly through predecessor and parallel projects of the projects involved. University-driven technology projects may start from ‘scratch’, but also based on previous research in a predecessor project. The existence of predecessor and parallel projects is an indication of available expertise within a research team which facilitates learning and increases the speed of commercialization, because the new project benefits from past knowledge accumulation, for example, answers to more basic questions are already available. Also, the existence of parallel projects may increase the speed of commercialization, due to economies of scale and synergy. Thus, the level of embedded-ness of a project in earlier/parallel projects is assumed to lead to higher efficiency and better performance.

Financial capital, as the other valuable resource, is conceptualized as the financial support available to carry out the project, provided by the university itself, public research foundations, large firms, and other sources. Generally speaking, financial support may speed up the process, because a larger team can be established (Utterback 1996; Christensen 2003). It should be noted that available funding could also be seen as an output of technology projects, reflecting research team performance in terms of attracting financial resources (Flegg and Allen 2007; Lee 2011). However, this study only uses financial support as a resource on the input side used by research teams to produce research and commercialization results.

On the output side, commercialization processes are faced with multiple outputs, a situation that is also emphasized by Perkmann and Walsh (2007), for example, the establishment of spin-off firms meant to develop an invention and bring it to market, parallel to other channels, like the collaboration between the university and a large firm or the licensing of a patent. In this study, the outcome of the commercialization line of the project is taken as the main outcome; this may vary between market introduction, continuation and project commercialization termination. As knowledge takes many channels, a terminated (ceased) commercialization effort does not mean that the project is useless, merely that the commercialization was not an optimum success.

Adopting a “production” approach to efficiency in general (Farrell 1957), the efficiency of the commercialization process can be modeled by taking projects as units (Decision Making Units, DMUs) that combine certain resources (named inputs), such as financial capital and knowledge, to produce certain outputs in bringing an invention to the market (specific for university research, Cherchye and Abeele 2005; Lee 2011). From an output-oriented perspective (Farrell 1957), efficiency is defined as the ratio of a unit's observed output to the maximum potential output given the input levels. Inputs in this study include the knowledge and expertise that exist in research teams or that are gained by working together with large firms, and funding that is available to the projects. With regard to knowledge, one may think of accumulated or additional knowledge and experience within the team achieved on the basis of related projects carried out earlier and parallel projects, leading to advantages of scale and synergy. Collaboration with large firms, the level of embedded-ness of projects (as accumulated knowledge), and financial capital are the main output variables to be explored in the efficiency analysis.

In this study, project efficiency is seen as a team's ability to leverage team knowledge through inputs, namely the new knowledge it acquires from external sources and collaboration with large firms. Thus, efficiency is included in the performance model as an indicator of realized absorptive capacity. A state of the art of studies on university-industry collaboration is presented in Appendix 1 and a more specific selection of studies at project level presented in Table 4.1.

Table 4.1. A summary of recent studies on technology projects

Author(s) and publication year	**Examines**	**Main outcomes**
Breznitz and Feldman (2012)	Universities' effort to evaluate their contribution to economic development in the US.	Universities are engaged in a wide range of topics with local communities, using these communities as labs to test new ideas to achieve social and economic goals.
Núñez-Sánchez et al. (2012)	Two types of scientific and techno-economic impacts of technology projects (between research centers and firms), and their determinants at project level in Spain.	The factors identified depend on different characteristics in public research centers and industrial firms, and the influence of these characteristics varies depending on the type of the impact considered.
Bekkers and Bodas Freitas (2011)	Different organizational structures, i.e. the knowledge goals, origin and finance lead to different performance outcomes using data from the Netherlands.	Industrial researchers with little experience in interacting with university are more likely to report high barriers to collaboration. Organizational structure is associated with the performance of the collaboration.
Bruneel et al.(2010)	The nature of the obstacles to collaboration between universities and industry and the influence of different mechanisms in lowering barriers drawing on data from UK.	The importance of having previous collaboration experience to engendering the trust required for success in collaboration.

4.2.2. Other factors influencing overall performance in commercialization

With regard to the overall performance of university-driven technology projects, aside from the efficiency factors, various other factors are included into the performance model, namely, the resource and capability of the team and its absorptive capacity, the nature of the invention elaborated in the project, characteristics of the market and business environment and other factors.

To be able to learn from external knowledge sources, research teams develop certain capabilities, allowing them to recognize, acquire and assimilate relevant new external knowledge, which defines their absorptive capacity (Zahra and George 2002; Lubatkin and Lane 1998). This applies specifically to bridging different cultures, academic versus business, while being involved in exploring the potential of the invention and in exploiting market opportunities. Thus, different capabilities within a research team of a technology project may affect team's learning possibilities and commercialization results (e.g. Simsek 2009; Datta 2011).

To bridge different worlds from the side of academia, managers need what is defined in this study as affinity. Additionally, the length of time that the manager has been active as a professor indicates the degree of accumulation of knowledge and experience, both in terms of subject matter and of organizational aspects, which in turn may increase the research team's absorptive capacity.

The accumulated knowledge and expertise (academic and non-academic) of a 'star scientist' as a leader of a research team could be an important resource for a team affecting absorptive capacity of the team and commercialization performance. 'Entrepreneurial scientist' (Etzkowitz 2008; Zucker et al. 1994; Zucker and Darby 1998), defined as a scientist that is more likely to perform better when it comes to commercialization. In this study, the manager of a team is called a 'star scientist', when he displays a high profile in winning prizes, filing patents, publications in top peer-reviewed journals and managing or advising firms. Accordingly, this factor is included in the performance model.

The market introduction of a new product or process depends, among other things, on the radical or incremental nature of the invention. Radical inventions require structural changes in infrastructures, like the fuel infrastructure in the case of electric cars, and in related social institutions, which is why they face more obstructions than inventions that are incremental and fit into existing structures (Geels 2004). Thus, we include the nature of the invention/innovation as an important factor in the performance model.

From a market point of view, it is expected that there will be differences in commercialization when a mass market is foreseen, like a fuel cell technology that results in replacing traditional batteries in a whole range of electronic devices, compared to a limited market, for instance lithography machines, with a small number of customers in the world (Tidd et al. 2009). Also, markets may vary in the level of regulation. When there is extensive regulation, for instance in markets for new drugs and tissue-engineering, market introduction is a long process, due to the required testing and approval procedures, much longer than in markets with less regulation (Utterback 1996; Tidd et al. 2009). There may be serious delays if regulations are tightened and specific methods of pre-clinical testing banned. Thus, envisaged market size and market regulation (level) are included as factors in the model.

The type of university may also play a role. A distinction can be made between science-based learning, for instance in the case of life sciences and nanotechnology, and problem-based and engineering types of learning with new applications or combinations of existing knowledge (know how), for instance the development of medical instruments and the automotive industry (Asheim et al. 2007; Tidd et al. 2009). Problem-based learning provides a greater incentive for collaborative learning between the various (regional) partners involved and it may proceed more quickly and accelerate knowledge commercialization, whereas science-based learning takes more time and is more often globally oriented. Firms and universities may differ in this respect, with technical universities putting a greater emphasis on applied, problem-based learning and engineering knowledge, and thus on collaborative learning with firms, compared to the science faculties of general universities.

And finally, the urban economic environment is included as a factor of influence. Agglomeration theory emphasizes the advantages of being located in large cities (Audretsch and Feldman 1996; Combes et al. 2011), including knowledge spill-overs, the availability of specialized workers and test markets, and access to global traffic nodes. A high density and variety in information and a strong presence of top professionals may improve creativity and enhance learning possibilities for bringing knowledge to the market in core metropolitan areas, compared to smaller cities in non-core regions (e.g. Florida 2002; Sassen 2005).

A conceptual model of the influencing factors to the performance of technology projects is presented in Figure 4.1.

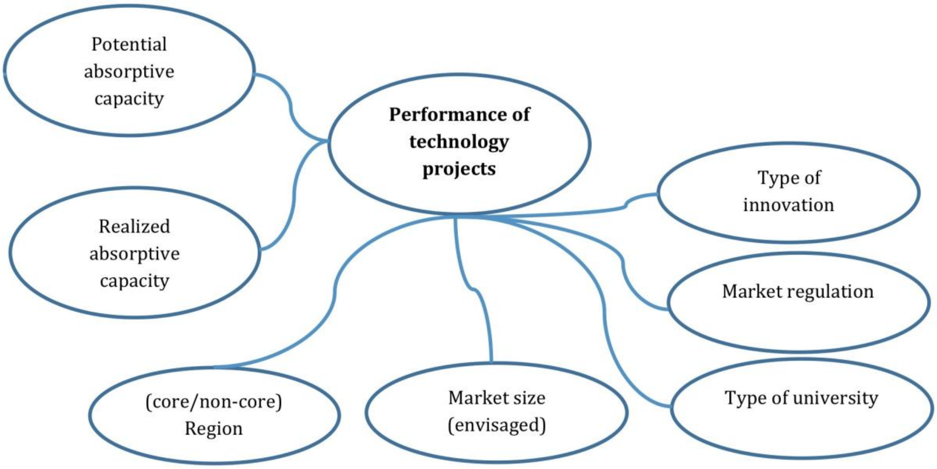

Figure 4.1. A conceptual model of commercialization performance of technology projects

4.3. Methodology, data and measurement

4.3.1. Data Envelop Analysis

Data envelop analysis (DEA), as a non-parametric approach, uses linear programming to build a piece-wise linear frontier and can be applied when there are multiple outputs without a meaningful aggregation (Coelli et al. 2005; Thursby and Kemp 2002), and when the number of decision-making units is limited. DEA uses the input and output data themselves to compute the production possibility frontier. The efficiency of each unit is measured as a ratio of weighted output to weighted input, where the weights are calculated to reflect the unit at its most efficient *relative to* all others in the data set, including an estimation of the distance function (to this frontier) (Shepherd 1970). Accordingly, DEA produces efficiency scores for each research project by first determining the set of technology projects which exhibit 'best practice' with regard to commercialization outcomes. Thus, for each research project in the sample, DEA determines whether it lies on the frontier and, if not, how 'far' from the frontier it lies. Units that lie on the frontier are called efficient and those that are not on the frontier are said to be inefficient. A simple example of a single output and a single input of six technology projects are presented in in Figure 4.2. The line linking A-D is the best practice frontier, among which no one dominates the others and each successively uses more input and produces more output. Technology projects E and F are dominated by others, for example, project C uses less input and produces more output compared to F. E and F lie below the efficiency frontier.

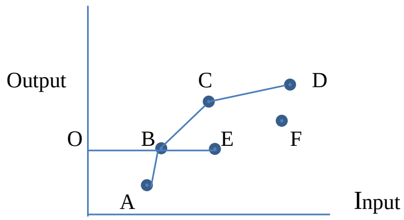

Figure 4.2. DEA production frontier

There are many models within DEA that can be distinguished according to their input or output orientation (Cooper et al. 2000). In an input orientation, outputs are assumed to be fixed, and the possibility of proportional reduction in inputs is explored, whereas in an output orientation approach, inputs are fixed, while the possibility of a proportional expansion of outputs is explored. The (input-oriented) efficiency of project E in Figure 4.2 is OB/OE. Because the main reason of this exploration is to develop recommendations on improving the performance of technology projects in terms of (the speed of) market introduction, the output-oriented model is used.

The DEA starts with a small number of inputs and outputs that are considered to be essential in evaluating the efficiency of university-driven technology projects in terms of commercialization outcomes, and more variables are added and their influence on the model results are studied through a forward procedure, while many different models are built and tested in the current analysis also suggested by Cooper et al. (2000). There are two procedures for the progressive selection of variables: a forward selection and a backward selection (Pastor et al. 2002). In this study the forward selection is used, in which the analysis starts with several input and output variables, and input variables are added one by one taking the production related factors into account, the aim being to produce sufficient differentiation by number of efficient DMUs.

The following steps are taken. Initially, DEA is applied to a data set of three inputs and two outputs, namely, years of collaboration with larger firms (input), financial investment capital (input), existence of predecessor and parallel project (input) and commercialization outcome of the projects (output) and satisfaction of the manager (output). Then, at each successive step, another relevant variable is added to the model and the additional efficient projects are identified. The rule that is adopted here is that the minimum number of projects should be three times greater than the number of inputs plus outputs (Lee 2011), and the number of input and output variables has to be limited to 3 and 2, respectively, in order to be able to interpret the results in a proper manner [42>3(3+2)]. Since this study is a first attempt to apply DEA to measure the efficiency of commercialization at project level, and the data set is given, the models are selected based on their commonality and applicability to the data set.

Constant return to scale (CRS) model or CCR (Charnes, Cooper and Rhodes 1978) and variable return to scale (VRS) models or BCC (Banker, Charnes and Cooper 1984) are used to measure the efficiency of technology projects. Moreover, Scale Efficiency (SE) is calculated for the projects (details about these models are provided in Note 1). Applying different types of models (CRS, VRS and SE) ensures the robustness of the results in evaluating project efficiency. Although the efficiency of projects using different models is somewhat different, there is a set of decision making-units (DMUs) that are efficient in all models. Constant return to scale (CRS) results are used further in the study.

4.3.2. Rough Set Analysis

DEA lacks any explanatory power of the performance of technology projects in terms of commercialization; it only provides 'labels' in terms of efficiency. Therefore, an extended model is used and rough-set analysis is applied in drawing on the 42 sampled projects, to identify the factors influencing the overall performance in terms of commercialization. The limited size of the sample and low level of measurement of some data, namely categorical, including a somewhat fuzzy character, prevented us from using regression analysis, instead of which we applied a fuzzy based analysis, rough-set analysis (e.g. Pawlak 1991; for details, see Polkowski and Skowron 1998, for a new approach, see Klopotek et al. 2010). In contrast to multiple regression analysis, no assumption is made in rough-set analysis about the distribution of the data, and the factors can be categorized. Data from the in-depth interviews with project managers is used to develop the information table with 42 technology projects, serving as a basis for a systematic analysis of commercial performance.

In rough-set analysis, data are presented in an information table, that is to say, a matrix in which rows are labelled by objects (in this study: projects) and columns are labelled by attributes (variables). Objects are arranged on the basis of their condition attributes (C) and decision attribute (D). These two types of attributes are analogous to the independent variables and the dependent variable used in regression analysis.

The starting point of rough-set theory is the indiscernibility (similarity) relation, generated by information about objects of interest. Assume an information table of U(G,M) is a set of objects G and a set of attributes M and a binary relation between the object g and the attribute m. For a given subset of attributes, the set of objects may be divided into *equivalence classes* or *indiscernibility classes*. For each subset $X \subseteq U$, one may define a *lower approximation* and an *upper approximation*. The lower approximation is defined as the union of all equivalence classes which are fully included in that of X. The upper approximation is defined as the union of all equivalence classes which have a non-empty intersection with that of X. Consider the subset of attributes {a1,a2} in Table 4.2. For the full set of objects A, the equivalence classes are: {o1,o3}{o2,o5}{o4}.

Table 4.2. A simplified information table

	a1	a2	a3	a4
O1	1	1	1	1
O2	1	0	0	0
O3	1	1	0	1
O4	0	1	0	1
O5	1	0	1	0

Considering now a subset of objects X={o1,o2,o3}. For the same subset of attributes {a1,a2}, the equivalence classes of X are: {o1,o3}{o2}.The *upper approximation* of X is:{o1,o3)+{o2,o5}= {o1,o2,o3,o5}. The *lower approximation* of X is: {o1,o3}. The rough-set is defined as a pair of sets corresponding to approximations, namely lower and the upper approximation of set X.

The basic procedure in rough-set analysis works through attribute reduction, i.e. finding a smaller set of attributes with the same or close classificatory power as the original set of attributes. On the basis of a reduced information table, decision rules are composed. A decision rule is presented in an “IF condition(s) THEN decision” format. The strength of decision rules is reflected in a measure named coverage, indicating the share of all objects displaying the same combination of condition attributes as well as the same outcome on the decision attribute.

4.3.3. Samples

In this study, we look at the commercialization time lines of university-driven technology projects, using a large database in the trend study and a small database for in-depth analysis. The trend study draws on 367 technology projects spread over two periods, with take-off in the years 1995 to 1997 and 2000 to 2002, to prevent bias from influence of the economic crisis of 2000. In addition, the projects are distributed among two regions in the Netherlands: the core metropolitan area or Randstad region and the Southeast of the country. The in-depth study draws on a sample of 42 technology projects, almost entirely selected from the trend study database in order to represent different commercialization outcomes, the two periods and the two regions. The in-depth study derives from semi-structured interviews that were conducted in 2010 with 33 research managers at universities (several managers were involved in more than one project).

4.3.4. Measurement

In the data envelop analysis (DEA), five input variables are explored and three of them are used to classify efficiency: financial support, collaboration with large firms and accumulated knowledge through parallel/predecessor projects.

The level of support may clearly influence the speed of development in the practical application and market introduction of an invention, as it affects the size of the team. At the same time, a four year period may be extended or not, while the university and (large) firms or other organizations involved may also provide financial support. Because it is difficult to obtain a complete picture, financial support as provided by STW, and eventually other (public) programs and others, is divided into two categories, a limited support and extended financial resources, according to the experience of the respondent (see also Table 4.4). The length of collaboration with a large firm is measured in years, whereas embeddedness in other projects (predecessor/parallel) is measured in three categories: no other projects exist (the one under study started from scratch and as a single project), one type of projects exists, and both exist. Two other indicators used in the exploration (amount of experience of the manager in holding the chair in the faculty and affinity with commercialization) are measured in terms of the number of years between starting the professorship and the end of the project or observation period (2010), and as affinity with commercialization using three categories as evidenced by the respondents, respectively.

The commercialization output of technology projects in the efficiency analysis is measured using various categories: terminated (ceased), partially continued, continued in research, continued in pilot, market introduction. In addition, the satisfaction of the manager with the commercialization outcome is also measured, using a scale from 1 to 10, to add a subjective dimension to the commercialization outcome. Filing a patent is not considered as a commercialization output, because it is not always relevant to market introduction, while it may also take place early in the commercialization process or later on.

It needs to be mentioned that the start of the commercialization process (line) is measured as “year in which for the first time the way to market introduction has been considered by the manager in a serious manner along various practical steps”. This could be years after the start of the STW project, e.g. after four years of PhD research, but also before ever receiving STW support.

Using rough-set analysis (RSA), aside from the influence of efficiency, three variables connected with the research and the research team are explored: the nature of the invention, being a star scientist, and type of university. The nature of the invention is measured in two categories (radical or incremental) according to the view of the respondent. Being a star scientist is measured as honoured by at least one large national award and successful in receiving grants from the National

Science Foundation (NWO), as well as grants from programs of applied national/European research. The type of university is measured in three categories: general, technical and a combination in the case of collaborative projects between these universities. A set of environmental influences concerning the market and urban location is also explored. Envisaged market size is assessed by the respondent and measured in three categories, whereas the level of regulation in the market is measured using three categories of strength, for example with new drugs and bio-implants in the most highly regulated market. And finally, the type of urban location in the Netherlands is measured in three categories, a core metropolitan area, a city outside the core, and a combination of cities following from collaboration between universities in different cities.

4.4. Descriptive analysis: trends and efficiency

First, the aggregate results regarding knowledge commercialization are presented in a trend study, followed by an exploration of efficiency using the in-depth sample.

4.4.1. Trend study of degree of commercialization

Table 4.3 indicates that, among older and younger university-driven technology projects, the share brought to market or use in society is 22 per cent and 15 per cent, respectively. The lower percentage for younger projects may be a consequence of the crisis, causing reluctance among firms to be involved, and the shorter time-span available, while a positive influence of a stronger awareness and efforts among younger projects could not compensate these negative impacts. In addition, failure is already relatively high among young projects, namely 26 per cent after five years, compared to the same share after 10 years for older projects. When we focus on older projects, it appears that 32 per cent was continued, while 20 per cent stagnated or the outcome is unknown. The large share of continuation after 10 years indicates that knowledge commercialization in technology areas may take a long time, which is confirmed for younger projects, of which almost 60 per cent is continued after five years.

Although the results of the trend study cannot be compared to the results in other countries, which makes it difficult to determine whether the share of projects leading to market introduction is high or low, the 22 per cent suggests that a higher share could be possible after 10 years. This justifies an exploration of the efficiency of technology projects in in-depth research, the more so because the question is whether more resources should be provided or existing resources need to be used more efficiently.

Table 4.3. Commercialization outcomes among younger and older technology projects

Type of outcome	Take-off in 1995-1997	Take-off in 2000-2002	Remarks
Failure after 5 or 10 years	54 26%	41 26% a)	
Stagnation, or development unknown after 10 years	42 20%	Not applicable	Subcategories are difficult to measure
Continuation	66 32% b)	94 59% c)	Often through financing by a firm, or by a new STW grant or other grant
Market introduction or use in society	47 22% b)	23 15% c)	Including non-commercial use in society
Totals	209 100%	158 100%	

a) failure measured only after 5 years
b) 10 years after project start
c) 5 years after project start
Source: Adapted from Van Geenhuizen (2013)

The projects in the in-depth sample are mainly drawn from the larger sample and are concerned with the major challenges of today (EU Horizon 2020), namely the medical sector (59.5 per cent), sustainable energy (materials), including energy saving (24 per cent), and solid waste and waste water treatment (9.5 per cent), while the rest has no direct connection to these challenges. Projects in the medical sector, namely, developing therapeutic drugs, diagnostics and tissue engineering (bio-implants) (28.6 per cent) are seen in this study as operating in highly regulated markets, which means long approval procedures and potential delay in commercialization processes. Some projects that develop improved surgery tools and imaging equipment are seen as subject to medium level regulation (28.6 per cent), while for the rest of projects, regulation levels are low (42.8 per cent). Sixty two per cent of the projects aim at incremental improvements to existing technologies, while 38 per cent are involved in radical innovations and breakthroughs.

Furthermore, 52 per cent of the sampled projects are carried out at universities in the core metropolitan area of the northern part (Amsterdam) and southern part of the Randstad region (Delft), while 31 per cent are conducted in the non-core south-east area (Eindhoven, Maastricht); the remaining 17 per cent are based on collaborations between universities in different regions in the Netherlands (see Table 4.4). Most of the projects are conducted at technical universities (55 per cent), followed by general universities (33 per cent) and collaboration between these universities (12 per cent).

With regard to absorptive capacity in the research team, the following can be stated (see Table 4.4). In total, 33 project leaders are involved, in four cases two leaders for one project and in several cases one leader for 2 or 3 projects. Most of them have a high to very high affinity with commercialization of technology (78 per cent), while the rest has a low affinity. Among the project leaders, 39 per cent can be qualified as so-called 'star scientists' (13 out of 33). By years of professorship within the frame of technology projects, project leaders at professorship level have achieved an experience of 12 years on average, with a standard deviation of 10 years. Moreover, most of the projects (78 per cent) benefit from predecessor and/or parallel projects.

With regard to the performance outcomes of technology projects in the in-depth sample, the descriptive statistics are as follows (Table 4.4 and Appendix 2). A market introduction occurred in 11 of the sampled projects (26 per cent), with more than half of the projects continued in pilot and research activities without bringing the main stream of the new knowledge to the market. The average time of commercialization activity, from the initial 'thoughts about commercialization' to market introduction, is 7.2 years, with a standard deviation of 4.3 years, while it takes between one year and 15 years to market the new product/process. Half of the projects were started in the mid-1990s, and the rest in the 2000s. However, in most cases, the commercialization process began later, namely when the research manager started making an effort to market the invention. More than half of the sampled projects 'produced' a spin-off firm, with an average time-span of five years between the establishment of a spin-off firm and the start of thinking about project commercialization. Most of the projects (67 percent) involved a patent.

Table 4.4. Descriptive statistics and classification in the rough-set model

List of variables	**Measurement and remarks**	**Classification in rough-set where applicable**
Number of projects	42	
A. Team resources and absorptive capacity(potential and realized)		
Affinity of project manager with commercialization (CA)	Measured in three categories	1: Small (21.5%) 2: Large (50%) 3: Very large (28.5%)
Years of experience of the project manager as a professor (DPR)	Time between starting the professorship and the end of project/observation (if a professor involved); Average:12.14; s.d.: 9.98; Min-max: 0-31	1: 0< X <= 5 yrs: (28.5%) 2: 5< X<= 10 yrs: (16.6%) 3: 10< X<= 20 yrs: (31%) 4: X> 20 yrs: (23.8%)
Star scientist	In two categories	1: Yes (39%) 2: No (61%)
Presence of parallel and predecessor projects	In three categories	1: Absence (21.5%) 2: Presence of predecessor or parallel project (50%) 3: Presence of both (28.5%)
Financial capital	In two categories	1: Limited financial resources 2: More financial resources
Efficiency level of project	Based on the results of DEA analysis (Model 1, Table 4.5)	1: Low efficiency (between 0.2-0.4): (40.5%) 2: Medium efficiency (0.5): (26.2%) 3: Large efficiency (between 0.6-1): (33.3%)
B. Resources through networks		
Duration of collaboration with large firms (DCF)	Time between starting the collaboration and the end of project	Average: 5.09; s.d.: 5.2; Min-max: 0-18
Collaboration with a large firm (relative) (DCFr)	Relative to commercialization period in three categories	1: no collaboration (35.7%) 2: 0 < X <=0.5: (33.3%) 3: 0.5< X <=1.5: (31%)
C. Other factors		
Nature of invention/innovation	In two categories	1: Radical (38%) 2: Incremental (62%)
Envisaged market size	In three categories	1: Small (35.7%) 2: Medium (16.7%) 3: Large (47.6%)
Market level regulation	In three categories	1: Low (42.8%) 2: Medium level (28.6%) 3: Heavy regulation (28.6%)
Type of university involved	In three categories	1: Technical (54.7%) 2: General (33.3%) 3: Combination due to collaboration (12%)
Region	In three categories	1: Non-core (31%) 2: Collaboration between regions (17%) 3: Core (52%)
D. Outcomes of technology projects in terms of commercialization result		
Performance of project in terms of commercialization	Measured based on commercialization outcomes and the years involved	1: Low (19%) 2: Medium low (38.1%) 3: Medium high (16.7%) 4: High (26.2%)

4.4.2. A focus on efficiency

A summary of the results of the CRS model is presented in Table 4.5. In Model 1, three input variables and two output variables are included that best describe the efficiency of the commercialization projects. Applying the CRS model, the following results are found:

- Eight projects have a score of one, which means that they are the most efficient ones, while six projects display slightly lower levels of efficiency (above 0.6 and less than one).
- Seventeen projects have low levels of efficiency (between 0.2 and 0.4).
- Eleven projects have medium levels of efficiency (0.5).

In addition, by including more input variables (Model 2), 16 projects show the highest level of efficiency. The correlation between Model 1 and Model 2 is high and significant (Spearman's rank correlation = 0.71), which underpins our decision to take the results of Model 1 into account in the next step of the study (efficiency variable), among other things because the number of efficient DMU's is only eight, allowing for more variation in the sample compared to Model 2.

First, a brief description is provided of the *profile* of most efficient projects, given the three input variables. Most efficient in terms of a quick market introduction results in the following profile: a low level of investment, benefits from a predecessor or parallel project, and no collaboration with a large firm.

Table 4.5. A summary of results of DEA analysis

Input and output variables	**Model 1**	**Model 2**
Duration of collaboration with large firms	*	*
Financial investment	*	*
Predecessor and/or parallel project	*	*
Manager's experience as a professor		*
Manager's affinity with commercialization		*
Outcomes in terms of commercialization	*	*
Manager's satisfaction with the outcomes	*	*
Average score	0.57	0.78
Standard deviation	0.24	0.24
Min	0.2	0.37
Number of efficient DMUs	8	16
Correlation with Model 1	-	0.71

Note that efficiency analysis draws on the idea of a *minimum* input of resources, which does not necessarily lead to a good performance in terms of market introduction (Table 4.6)

- Thirty six per cent (n=15) has medium and high levels of efficiency (>=0.5) and high and medium high performance levels.
- Thirty three per cent of the projects (n=14) show a low score on efficiency (<=0.4) as well as a low and medium low score on performance.
- A small number of projects with a relatively low level of efficiency (<=0.4) has a medium-high and high level of performance (7 percent), while ten projects with a medium and high efficiency score (>=0.5) shows a low and medium low performance level (24 percent).

Moreover, the difference between the groups is significant ($p<0.05$), which supports the conclusion that there is a positive association between project efficiency and project performance, such that projects with high efficiency levels are more likely to show high performance high levels, while projects with low levels of efficiency are more likely to perform poorly. More details are provided in Table 4.6.

Table 4.6. Relationship between project efficiency and project commercialization performance

	Efficiency level			
Commercialization performance	**Low (0.2-0.4)**	**Medium (0.5)**	**High (0.6-1)**	**Total**
Low	4	1	3	8 (19%)
Medium-low	10	3	3	16 (38.1%)
Medium- high and High	3	7	8	18 (42.9%)
Total	17 (40.5%)	11 (26.2%)	14 (33.3%)	42 (100%)
	Pearson $chi^2(6)$ =12.96, P=0.04			

4.5. What determines the overall performance in commercialization?

The overall performance of university-driven technology projects is measured through a variable taking commercialization outcomes and the years of commercialization (duration) into account. If a commercialization line ceases after a long time, the project is assigned the lowest score, while a project that is launched to the market, especially in a short time, is assigned the highest score. This type of scaling, including a check for robustness, produces the following performance as the decision variable in the rough-set analysis (RSA): 11 projects (26.2 per cent) show the best performance, eight projects (19 per cent) the worst, and all others in between: medium low (38.1 per cent) and medium high (16.7 per cent).

The following steps are taken to build the information table and to experiment with this table in identifying the best rough-set models:

- Firstly, in preparation of the data, the level of measurement of variables is revised, as the continuous level increases the number of rules produced and reduces the interpretability. Accordingly, to avoid having too many decision rules, several continuous variables are transformed into categorical variables, followed by robustness checks (see Table 4.4. and Appendix 2).

- Secondly, as model experimentation, the models are improved by adding various variables stepwise, with the aim of increasing the number of variables in the core, the quality of the core, the strength and coverage of the rules, and the frequency of attributes in the rules, at each step. A check of different borderlines for the decision attribute is also performed.
- Thirdly, as a result, the best model is reached by strength, coverage and interpretability of the results, showing that the quality of the rough-set approximation is 1, as an indication that the reliability of the classification for the decision attribute and the overall quality of the classification is at its maximum.

The best model is presented in Table 4.7, along with the three best rules in terms of their strength and coverage. In the model, the three condition attributes (affinity of the project manager with commercialization, duration of collaboration with large firms and efficiency of the projects) appear in the core.

Table 4.7. Three strongest rules produced by the optimum variable set and their coverage

No	**Rule**	**Decision attribute (performance)**	**Coverage (nr. of projects)**	**Strength (%)**
1	CA=1 & DCFr=2	Low	6	75
2	DCFr=3 & Efficiency=1	Medium low	6	37.5
3	DCFr=3 & Efficiency=2	High	4	36.4

Selected condition attributes:
CA (commercialization affinity of manager): 1: small; 2: large; 3: very large
DCFr (duration of collaboration with large firms relative to commercialization period): 1: no collaboration; 2: 0< X <=0.5; 3: 0.5< X <=1.5
Efficiency: 1: low (between 0.2-0.4); 2: medium (0.5); 3: high (between 0.6-1)

The results of the best model can be summarized as follows:

- Among the rules, three are best when considering the number of projects covered and the strength of the rule (Table 4.7). *Rule 1* is the best, given a strength of 75 per cent and a coverage of six projects. The rule indicates that, if the affinity of the project manager with commercialization is low and the relative years of collaboration with large firms is less than 0.5, then the performance is poor. *Rule 2*, with a coverage of six projects and a strength of 37.5 percent, indicates that a longer relative duration of collaboration with large firms (between 0.5 and 1.5) and a low level of commercialization efficiency (less than 0.4), produce a medium low performance level. *Rule 3*, with a coverage of four projects and strength of 36.4 percent, indicates that a longer relative duration of collaboration with large firms (between 0.5 and 1.5), together with medium efficiency levels (50 per cent) produce the best results in terms of commercialization.

While type of region is included in the analysis as a condition attribute, the results show that it is not an influencing factor in the best three models of commercialization presented.

Furthermore, the next best model is explored by excluding the condition attribute 'years of collaboration with a large firm (relative)' from the model and including the following four condition attributes: affinity of the project manager with commercialization, years of experience of the project manager as a professor, efficiency of the technology projects, and envisaged size of the customer market. Under these conditions, the model reaches a quality of classification of the attributes/attributes in the core of 0.70/0.70. This result is weaker than that of the previous model. The three best rules are presented in Table 4.8.

Table 4.8. Three strongest rules produced excluding collaboration with a large firm

No	Rule	Decision attribute (performance)	Coverage (no of projects)	Strength (%)
1	CA=1 & MS=1	Low	3	37.5
2	DPR=3 & Efficiency=1	Medium low	5	31.25
3	MS=3 & CA=3 & Efficiency=1	Medium low	3	18.75

Selected condition attributes:
CA (commercialization affinity): 1: small; 2: large; 3: very large
DPR (duration of professorship): 1: 0< X <=5 yrs; 2: 5< X <=10 yrs; 3:10< X <=20 yrs; 4: X>20 yrs
Efficiency: 1: low (between 0.2-0.4); 2: medium (0.5); 3: high (between 0.6-1)
MS (Market size envisaged): 1: small; 2: medium; 3: large

The results can be summarized as follows:

- Rule 1 is the strongest rule, with a strength of 37.5 per cent, indicating that a low level of affinity of the manager with commercialization and a small size of the customer market result in the lowest level of performance. This rule can be understood as follows: if the manager does not care about commercialization aimed at introducing the invention to the market and the market is also expected to be small, it is likely that the product/process will not reach the market in a short time.

- Rule 2 shows the highest coverage (5 out of 16 projects) and indicates that having more years of experience as a professor (between 10 and 20 years) and a low level of efficiency of projects lead to a medium low level of project performance. This rule suggests that professors with many years of experience may find it difficult to move towards commercialization, due to a different routine for years and a lack of absorptive capacity in the team.

- Rule 3, with a strength of 18.75 percent, indicates that a large size of customer market and very large level of affinity of the manager with commercialization, together with a low level of efficiency of projects keep the performance of projects at a medium low level. This rule suggests that a lack of realized absorptive capacity in the team, in terms of efficiency, is an important factor blocking a quick commercialization.

The overall results from the 'qualitative' correlation analysis discussed above indicate that the years of working together with a large firm have an important influence. However, all strong outcomes point to an important combination between this collaboration and absorptive capacity attributes, like project efficiency (best model outcomes and influence on medium level) and affinity of the manager with commercialization (negative influence). Affinity of the manager with commercialization activity tends to be an important factor and a lack of it has a negative influence on the performance of commercialization, while the presence of affinity indicates that the individual manager is able to focus on scientific and commercial objectives simultaneously. Moreover, a positive relationship between project efficiency and project performance is strongly suggested by the analysis, meaning that project teams using more resources producing outputs are less likely to bring the knowledge to the market in a shorter time.

4.6. Conclusion

Despite the *European knowledge paradox*, indicating a possible failure to 'convert' academic research into products and processes used in the market (Tijssen and van Wijk 1999; Dosi et al. 2006), university-driven technology projects and the level of success of the projects attracted small attention (Perkmann and Walsch 2007; Núñez-Sánchez et al. 2012). This study is an attempt to respond to these shortages taking a sample of 367 technology projects spread over two periods, with take-off in the years 1995 to 1997 and 2000 to 2002, and an in-depth sample of 42 technology projects drawn from the large sample to present different commercialization outcomes. Moreover, the efficiency and performance of university-driven technology projects in terms of commercialization were measured, which is among the first of its kind in empirical studies. Given a relatively low level of actual market introduction of university-driven technology projects of 22 per cent, two characteristics of commercialization were explored in this chapter, efficiency and overall performance. Efficiency was measured based on outputs of the commercialization and satisfaction of the manager, while including the following inputs; financial resources, networking resources (years of collaboration with large firms) and team resources (presence of predecessor and parallel projects). Data envelop analysis (DEA) was applied to identify the frontier set of the most efficient projects. Most efficient in terms of market introduction tends to be the following profile: a low level of investment, the existence of a predecessor or parallel project, and no collaboration with a large firm, although it must be mentioned that efficiency analysis draws on the idea of minimizing input of resources keeping the same outputs, which does not always coincide with the best results in terms of commercialization. This may have implications for the stakeholders involved in commercialization of university knowledge since low efficiency (producing outputs using more inputs) is an important factor results in low commercialization performance.

Next, the scores from DEA were used in an exploratory analysis of overall project performance, in terms of commercialization, alongside some other factors. Using rough-set analysis (RSA), the results achieved were stated in terms of rules, indicating the following trends. Duration of collaboration with large firms and research project efficiency were found to be important influences on the basis of their highest frequency among the strongest rules. In addition, based on the strongest rule, a small affinity of the project manager with commercialization, coupled with short collaboration with a large firm, proved to be an important predictor of poor performance. By contrast, a longer period of collaboration with large firms, together with medium efficiency levels (50 per cent), produces the *best* results in terms of launching the product into the market and short commercialization period. Furthermore, the regional component was found not to be important in the strongest rules. When exploring a next best model, it was found that, if the manager has a small affinity with commercialization (a low absorptive capacity) and the market is also expected to be small, the commercialization reaches its lowest performance level. Moreover, managers with higher levels of experience (longer periods) may find it difficult to move towards commercialization if market opportunities are not clear. Overall, the efficiency analysis leads to somewhat different results compared to the analysis of overall project performance, although there is a positive relationship. The different underlying principles can be illustrated by collaboration with large firms. In efficiency analysis, this collaboration should be at its minimum as a resource, while in the overall analysis, a longer collaboration tends to have a positive effect on better performance in terms of commercialization.

The study also had some limitations. Firstly, the study drew on an existing data set, meaning that the selection of the input and output variables was limited to the available data. Several variables, for instance precise data on financial investment and the size of research teams, were not available, unlike similar types of study (Cherchye and Abeele 2005; Lee 2011). However, it should also be recognized that funding from a particular program is often accompanied by additional funding, e.g. by the university or other programs. As a second limitation, the study is an elaboration of data provided by Technology Foundation STW and the projects involved went through a selection procedure for investment by this foundation. As a result, the university-driven technology projects included in the sample set may not be entirely representative of the larger population. However, as previously indicated, many of such projects have also obtained financial support via other ways, which increases the representativeness of the university-driven technology projects in the study. Thirdly, our in-depth study used a relatively small sample, which forced us to use rough-set analysis. Accordingly, future studies may use larger samples and use stronger techniques to identify, for example, non-linear relationships. However, it needs to be recognized that knowledge is ‘fluid’, sometimes causing fuzzy borderlines in the classification of commercialization of the knowledge, a situation with which rough-set analysis clearly complies. Moreover, other influencing factors, such as the structure of institutions in shaping university-industry relationships and accelerating commercialization projects (Perkmann and Walsh 2007), could not be taken into account in this study, but these may be investigated in the future.

Although the analysis discussed above only produced trends, some of these trends are interesting from a policy point of view, one of them being the role of collaboration with large firms. Ways need to be found to bring academic researchers into contact with large firms more easily, and to make them better understand - possibly through courses - how firms operate in terms of strategy reformulation and negotiations - and what obstacles may be expected and how to overcome them. Some universities have already opened a part of their laboratory to interact creatively with selected firms, and so-called living labs may act as places of interaction, and bridge the distance with firms and customer groups. A lack of affinity on the part of researchers with commercialization is also of interest from a policy perspective. Needless to say, basic/fundamental research should keep its place at university, but it is necessary to create positions and academic career perspectives (tenure track) for researchers with a strong affinity with commercialization and good results in this field. Moreover, commercialization portfolios need to be balanced to include high risk projects that do not yet have appealing markets on the horizon, and lower risk projects with sufficiently large envisaged markets.

Note 1

Using CRS model, the efficiency of any project like E below the production frontier is calculated: DEA-CRS: OB/OE and if E locates on GB line (the same point as B) the efficiency is equal to 0.

The line connects A-D is the frontier using VRS model. The efficiency of any project like E below the production frontier is calculated as follows and if E locates on A-D line (the same point as B) the efficiency is equal to 0: DEA-VRS: OB/OE.

Scale efficiency is calculated from CRS and VRS calculations through following formula:

SE: CRS/VRS= (OB/OE)/(OB/OE)=1

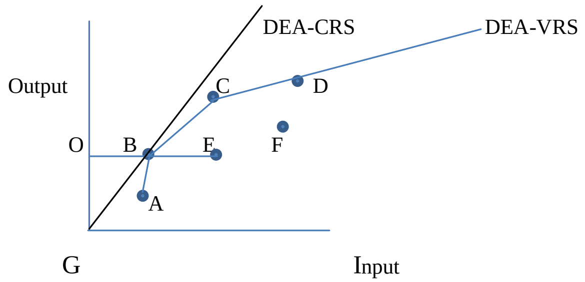

Figure 4.3. DEA production frontier including CRS and VRS models

Appendix 1

Table 4.9. State of the art on university-industry knowledge transfer and collaboration research 2006-2013

Author(s) and pub. year	Goal of analysis	Type of research / data	Main outcomes
Bozeman et al. (2013)	Examination of literature on research collaboration, specially on individual-level collaborations among university researchers	Qualitative, data from different countries	More attention to multiple levels of analysis and the interactions among them are needed
Kim (2013)	Examination of individual university productivity in technology transfer	Quantitative , panel data gathered over 1999-2007 from US universities	1.University's technology transfer activities were relatively efficient. 2.Universities and public policy should pay attention to stimulate commercial activities rather than to increase investments for upgrading a next level of long-term strategies.
Van Geenhuizen (2013)	Examination of what extent of technology inventions is brought to market and which factors hamper such a development.	Quantitative, 370 technology projects covering different regions in the Netherlands	1.The outcomes of collaborative projects and the barriers are identified. 2. Extended use of tools facilitate and accelerate market introduction, namely, living labs, are proposed.
Breznitz and Feldman (2012)	Examination of efforts taken by universities in the United States to evaluate their contribution to economic development	Qualitative, data from US	Universities are engaged in a wide range of topics with local communities, using these communities as labs to test new ideas to achieve social and economic goals.
Núñez-Sánchez et al. (2012)	Examination of two types of scientific and techno-economic impacts of technology projects and their determinants are analyzed.	Quantitative, data at project level from Spain	The factors identified depend on different characteristics in public research centers and industrial firms, and the influence of these characteristics varies depending on the type of impact considered.
Van Looy et al. (2011)	Examination of the extent to which scientific productivity affect entrepreneurial effectiveness.	Quantitative, data on 105 universities from 14 European countries	Scientific productivity is positively associated with entrepreneurial effectiveness.

Author(s) and pub. year	Goal of analysis	Type of research / data	Main outcomes
Bekkers and Bodas Freitas (2011)	Examination of different organizational structures of collaboration, i.e. the knowledge/technology goals, origin, finance and forms of interaction lead to different performance outcomes	Case studies and survey data from the Netherlands	1.Industrial researchers have little experience in interacting with university are more likely to report high barriers to collaboration 2. The organizational structure is associated with the performance of the collaboration.
D'Este and Perkmann (2011)	Examination of motivations by academic scientists to engage with industry	Quantitative, survey data for a large sample of UK investigators in the physical and engineering	1. Most academics engage with industry to further their research rather than to commercialize their knowledge. 2. Four main motivations: commercialization, learning, access to funding and access to in-kind resources.
Bruneel et al.(2010)	Examination of the nature of the obstacles to collaborations between universities and industry and exploring the influence of different mechanisms in lowering barriers	Quantitative, drawing on a large-scale survey and public records from UK	The importance of having previous collaboration experience to engender the trust required for success in collaboration.
Bekkers (2010)	Examination of incentives and policies at EU level that affect the knowledge transfer activities of individual researchers as well as research institutes such as universities and Public Research Organisations (Review paper)	Qualitative from different European countries	1.University involvement in university based patents is higher than official data suggests and is not much below the US level. 2.Many patents with academic inventors are assigned to companies, and this is even a more successful way of technology transfer than university-owned patents. 3. Europeans' research performance is constrained by problems affecting both the demand and supply of high-quality public research rather than only the transfer process between university and industry

Author(s) and pub. year	**Goal of analysis**	**Type of research / data**	**Main outcomes**
Geuna and Muscio (2009)	Examination of university knowledge transfer models and recent developments in literature on research collaborations, namely, intellectual property rights and spin-offs	Qualitative from different countries (literature review)	1. The diversity in the institutionalization of public research across the EU countries has resulted in heterogeneity in Knowledge transfer (KTO) institutions, such as TTOs. 2. The importance of previous management experience in KTO staff is revealed; the need for the office to reach a critical size for it to be effective in its different tasks and a need for regional offices rather than small offices in individual universities.
Bekkers and Bodas Freitas (2008)	Examination of the importance of different channels through which knowledge and technology are being transferred between universities and industry in different contexts	Quantitative, data collected from May to June 2006, based on two questionnaires aimed at Dutch university and industry researchers	1.Industrial activity of firms does not explain differences in importance of wide variety of channels of knowledge transfer between university and industry. 2.This variety is better explained by disciplinary origin, the characteristics of the underlying knowledge, the characteristics of researchers involved in producing and using this knowledge and the environment in which knowledge is produced and used.
Bercovitz and Feldman (2006)	Examination of university–industry relationships and their role in knowledge-based innovation systems	Qualitative, data mainly from US	Patenting and licensing activities of medical schools faculty decrease with the age of faculty.

Appendix 2

Table 4.10. Variables measuring the performance and outcomes of commercialization of technology projects

List of variables	**remarks**	**Measurement**
Performance of project in terms of commercialization	Measured based on commercialization outcomes and the years involved	1: Low (19%) 2: Medium low (38.1%) 3: Medium high (16.7%) 4: High (26.2%)
Outcomes in terms of commercialization project	Measured in five categories	Ceased (16.5%) Partially continued (5%) Continued in research (43%) Continued in pilot (9.5%) Market introduction (26%)
Satisfaction of the project manager with commercialization	Ranked from 1 to 10	Average: 7.07; s.d.: 1.41; Min-max: 4-9
Time to establishing a spin-off firm	Time between the first commercialization thoughts and establishment of a spin-off (n=23)	Average: 5.43; s.d.: 4.34; Min-max: 0-20
Time to launch to the market	Time between the first commercialization thoughts and launch to the market (n=11)	Average: 7.18; s.d.: 4.31; Min-max: 1-15

(n=42)

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How Absorptive Capacity Through Education and Training Drives Firms' International Knowledge Networks*

Abstract

Industrial competence is increasingly dispersed across the globe, urging high-technology firms to build knowledge relationships with partners across national and continental boundaries. In this chapter, the role of the absorptive capacity of university spin-off firms in two European countries in this activity is examined, specially the spatial reach involved, because only with a larger reach new hotspots of R&D and innovation can be connected. It is found that around 62 per cent of the spin-off firms employed knowledge relationships abroad, almost 34 per cent of them outside of Europe. The main underlying absorptive capacity factors are education level (PhD), market- and business-related training, and newness of innovations.

5.1. Introduction

Different from the previous chapter, this chapter is concerned with spin-off firms, as the other channel of commercialization of university knowledge central in the thesis. The impact of different absorptive capacity characteristics on distant knowledge relationships is investigated.

It is generally acknowledged that firms that are embedded in networks of inter-firm and inter-organizational knowledge relationships absorb a wide range of specialized knowledge and, as a result, perform better (Grant 1996; Malerba and Orsenigo 2000; Powell et al. 1996; Tether 2002). Since the early 1990s, the increased global competition has produced a continuous pressure on high-technology firms to improve their technological, organizational and market-related knowledge, and to do this in part through collaborative networks. More recent studies indicate the importance of knowledge collaboration on a *global* level (Kuemmerle 2002; Clercq et al. 2012); this is because industrial competence is now widely dispersed all over the globe, whereas increased specialization has limited the availability of specialized knowledge to only a few places in the world (Teece 1992; Amin and Cohendet 2006). The OECD in its latest Science, Technology and Industry Scoreboard (2011) finds an increased role in international research collaboration for countries like China, Korea, Brazil and India. In R&D investment the US is in first position and is followed by China, just ahead of Japan, whereas Korea equals the UK (OECD 2011). This changing landscape of R&D and

* A modified version of this chapter, M.Taheri as the first author, co-authored by Marina van Geenhuizen, was published in Papers in Regional Science in March 2011. The material underpinning Propositions 2.1 and 4.2 posed in Chapter 2 are not directly presented in this chapter but in the overall reflection on propositions as discussed in Chapters 8.

knowledge collaboration thus urges young high-technology firms to increasingly cross larger distances to acquire competitive knowledge. The need for internationalization among small and medium-sized enterprises is also generally acknowledged by the European Commission (e.g., EC 2010).

This chapter examines the factors that determine the spatial reach in gaining knowledge by young technology-based firms. There are two contrasting types of urban locations given theoretical ideas of agglomeration advantages. First is the large city or metropolitan area, where new knowledge is abundantly available in local settings, enabling young technology-based firms to benefit from knowledge spillovers and collaboration with partners in close proximity (Audretsch and Feldman 1996; Maskell and Malmberg 1999; Cooke 2002). By contrast, small towns in remote regions are facing a relative shortage in information and knowledge making firms to respond to local knowledge deficiencies by crossing borders and extending their reach, as shown by de Jong and Freel (2010). However, in innovation theory that draws on the concept of absorptive capacity and the development of different innovation strategies (Cohen and Levinthal 1989; Freeman 1982) the stance is taken that knowledge networks may extend from a local to a global level, anyway, with local proximity in a less pronounced role (Boschma 2005; Laursen and Salter 2004). In this chapter, the two types of arguments are explored, with a focus on the role of absorptive capacity as the dynamic capacity that enables firms to create value and gain competitive advantage through the management of internal and external knowledge.

The focal attention in this chapter is on university spin-offs, which are firms that develop and commercialize knowledge created at universities or research institutes. Attention to these types of firm has become important in the regional and national policies in the European Union since the early 1980s, especially since the early 2000s (Huggins and Johnston 2009). University spin-offs are viewed as developers of university inventions towards market applications, as contributors to a wider diffusion of university knowledge, as promoters of entrepreneurship in the region and as supporters of high-technology infrastructures (Debackere and Veugelers 2005; Shane 2004). However, in most European Union countries, spin-offs' growth has been slow (Mustar et al. 2006; Colombo and Grilli 2010). Thus, one of the policy needs involves figuring out under which conditions spin-offs source knowledge abroad and how this can be enhanced in the context of accelerating growth.

With regard to absorptive capacity, four major knowledge gaps can be observed in the literature. First of all, there is a gap regarding the role of absorptive capacity in knowledge networking abroad, including distances, which has been included just recently in research agenda's (Xia and Roper 2008; de Jong and Freel 2010; Clercq et al. 2012; Liu 2012; Fletcher and Harris 2012). Secondly, there is a need for an extended approach and measurement of absorptive capacity which often have been limited to R&D indicators (Escribano et al. 2009; de Jong and Freel 2010;

Murovec and Prodan 2009). Thirdly, the influence of the knowledge deficiency in remote regions on the development of knowledge relationships has received little attention to date, with a few exceptions (Isaksen and Onsager 2010; de Jong and Freel 2010). Fourthly, to our knowledge, the absorptive capacity of the focal category of firms in this chapter, university spin-offs, and its influence on their ability to build knowledge relationships abroad, has been not yet studied.

With a focus on the role of absorptive capacity in knowledge networking and drawing on interview data from 105 spin-off firms in Western Europe, the paper makes four contributions to the empirical literature. First, insight into spatial reach in knowledge networking, because knowledge networking is seen increasingly necessary over larger distances from Europe, to South Korea, China, India, and Brazil, aside from e.g. the US. Second, an extended approach to potential absorptive capacity, more than merely R&D, with the outcome that the individual quality of founders, holding a PhD and participation in training, matters as it increases the chance of a large spatial reach. Third, a confirmation of the influence of location in a remote region, with the outcome that firms in remote towns face a larger chance for a large spatial reach, however, with the limitation that the presence of global players in the region and a different willingness in larger countries to bridge large distance could be part of the explanation; and fourth, extension of empirical research on absorptive capacity and knowledge relationships abroad to university spin-off firms, which is entirely new.

The chapter unfolds as follows. The theoretical perspectives and model development are discussed in section 5.2. The methodological steps are explained next in section 5.3, followed by a discussion of the descriptive analysis and multivariate analysis of spatial reach in knowledge networking, drawing on the results from our interviews in section 5.4. The chapter concludes with a discussion section and reflects on the outcomes (5.5).

5.2. Theoretical views and model building

5.2.1. Resource-based view

The establishment of knowledge networks between countries is influenced by circumstances in the 'home' country as well as circumstances in the 'host' country. For example, the last might have a 'preferred status' in economic collaboration and trade, due to historical and cultural linkages, facilitating the founding of networks. Also, the 'host' country or a particular region might have a positive image, like Silicon Valley in the US (Saxenian 1994; Boschma 2005). The current paper, however, is limited to situations in the 'home' country, especially on the level of individual firms and their different resources for networking abroad.

According to resource-based views, firms are 'bundles' of resources that are used to create products or services that provide value to customers in a competitive environment. Firms' resources are the set of tangible and intangible resources tied semi-permanently to those firms, like capital owned, research facilities, and experience feeding absorptive capacity. Firms compete to possess resources that are rare and hard to imitate to gain a sustained competitive advantage over other firms (Penrose 1959; Barney and Clark 2007; Barney et al. 2011). Absorptive capacity as the ability of a firm to recognize, acquire and to assimilate and exploit external knowledge, is clearly one of the major resources of the firm (Cohen and Levinthal 1989). The concept of absorptive capacity recognizes that firms are in the position to understand, adopt and integrate know how generated elsewhere, meaning that various innovation options are open to firms. In theory, a wider and more diverse search strategy for new knowledge is seen to enable the creation of more opportunities to access and integrate highly specific sets of new knowledge, leading to different pattern of innovation and firm performance (Freeman 1982; March 1991; Nelson and Winter 1982; Teece 2007; West and Noel 2009).

The relationship between resources, including absorptive capacity, and 'acquiring global knowledge' is two-fold, allowing for various strategies: firstly, firms may acquire unique knowledge abroad as a valuable resource and grow in competitiveness; and secondly, establishing knowledge relationships abroad requires the 'investment' of particular resources. Resources are needed to overcome particular barriers to operate internationally and to sufficiently benefit from the interaction. Four main categories of barriers faced by innovative small and medium enterprises have been identified, including (1) resource barriers, namely, finance, lack of human capital, lack of management resources, (2) information and network barriers, namely, lack of knowledge on foreign markets and inability to contact potential customers abroad to identify foreign business opportunities, (3) cultural barriers, namely, lack of awareness of local cultural norms, languages and cultural differences and (4) legal/regulatory barriers, namely, financial and tax regulation product standards and patent and trademark issues (BIS 2010).

With regard to resources needed, much attention has been given to previous higher education and international (pre-start) experience in a wider context of business processes (Reuber and Fisher 1997; Colombo and Grilli 2005). Existing knowledge shapes a firm's absorptive capacity and allows it to recognize and acquire new knowledge on potential networks and use that knowledge later (Todorova and Durisin 2007). The networks through which spin-off firms could acquire external knowledge are named knowledge networks in this study. Two types of scarce knowledge are important here; firstly, following from barriers in local markets abroad, for example, in the form of particular customer requirements and regulation and industry standards, and secondly, on highly specialized technology that is available in a few 'hot spots' in the world (Oviatt and McDougall 1994; Prashantham 2005).

University spin-offs are a specific type of young firms, because they are often in need of resources, both ones that fulfill a basic need, like investment capital, and ones that are unique and provide a competitive edge. In this study, we define university spin-offs as firms that are established by university staff members or (graduated) students with the primary aim of bringing new university knowledge to market (Pirnay et al. 2003; Shane 2004). In recent years, they have been studied extensively (for overviews, see Mustar et al. 2006; Rothaermel et al. 2007; Djokovic and Soutaris 2008). What makes this type of firm different from young high-technology firms in general is that they originate from a non-commercial environment, in many cases, a technology research environment, which implies that, apart from the technology or invention, the entrepreneur is basically in need of complementary technical knowledge to develop a marketable product, and knowledge regarding customer requirements, changing market demands, pricing, etc. (Lockett et al. 2005; van Geenhuizen and Soetanto 2009). Connecting with (potential) customers, suppliers and knowledge institutes, as well as regular conferences or exhibitions, are thus highly valuable to the innovation and growth of spin-off firms in the early development stages.

Resources are not always owned individually, they may also be shared by a set of firms, for instance the ‘shared’ resources in clusters of firms or in large cities. The theory on agglomeration advantages of large cities suggests that young high-technology firms are likely to benefit collectively from knowledge spillovers and from collaboration with diverse partners in close physical proximity (Jacobs 1969) partly based on the assumption that tacit knowledge is mainly locally available (Audretsch and Feldman 1996; Maskell and Malmberg 1999; Cooke 2002). Accordingly, the perceived need to go abroad is less strong for these firms compared to firms in small towns in remote regions. Other studies emphasize the different knowledge needs and capabilities of individual entrepreneurs (e.g. Clarysse et al. 2011). In this vein, since the early 2000s, much doubt has been cast on the idea that physical proximity is a necessary condition for innovation and knowledge collaboration (Boschma 2005; Tödtling and Trippl 2005; Faulconbridge 2006; Torré 2008). A central argument is that young high-technology firms vary in absorptive capacity causing different levels of innovativeness, product-market combinations, etc., defining their knowledge needs, and also causing a different ability to cross cultural and institutional borders in search of new knowledge, all of which means that knowledge networks evolve on a variety of geographical scales (van Geenhuizen and Nijkamp 2012).

5.2.2. Focus on absorptive capacity

With regard to absorptive capacity, Zahra and George (2002) distinguish two dimensions, potential absorptive capacity (PACAP) and realized absorptive capacity (RACAP). PACAP makes the firm eager to acquire new knowledge and allows it to acquire and assimilate external knowledge (Lubatkin and Lane 1998) while RACAP allows the firm to leverage its knowledge by using the knowledge it has absorbed. This distinction emphasizes the fact that a firm may acquire and assimilate knowledge, but may lack the ability to transform and exploit it for innovation or profit generation.

By adopting the above conceptualization of absorptive capacity, it can be argued that firms with greater absorptive capacity are better equipped to identify and exploit external knowledge that is useful, bridging larger distances if necessary (Escribano et al. 2009; Huber 1991). Accordingly, the assumption is that several characteristics of founding entrepreneurs or founding teams, such as pre-start working experience and level of education, are important dimensions of absorptive capacity as skills, expertise, understanding, etc. that have been gathered previously, thereby referring to *potential* absorptive capacity. When spin-offs have a strong potential absorptive capacity, among other things through PhD experience, they are better equipped to overcome barriers in sourcing knowledge abroad, like language and cultural barriers, which are found in studies as an important factor in establishing knowledge relationships (BIS 2010; Lane et al. 2001; Liu 2012). An additional component of potential absorptive capacity is *cross-cultural experience* in the founding team, through living experience and/or family ties abroad. Cross-cultural experience can reduce cultural distances between partners in different countries, leading to a higher degree of involvement in firms abroad (Boschma 2005; Nooteboom 2009; Hart and Acs 2011; Liu 2012).

In addition, *realized* absorptive capacity refers to the ability to leverage existing knowledge and make particular choices. This may be evidenced by the actual stage in product development and level of newness of innovations (Nooteboom et al. 2005; Fabrizio 2009). Young high-technology firms are involved in different phases of new product development, including the early development stage, pilot stage, market access stage and established market position, each showing different components of absorptive capacity. Similarly, highly innovative breakthroughs that are protected by patents show a different kind of ability to establish knowledge relationships compared to incremental improvements (e.g. Andersen 2006).

A conceptual model of spatial reach in knowledge relationships is presented in Figure 5.1.

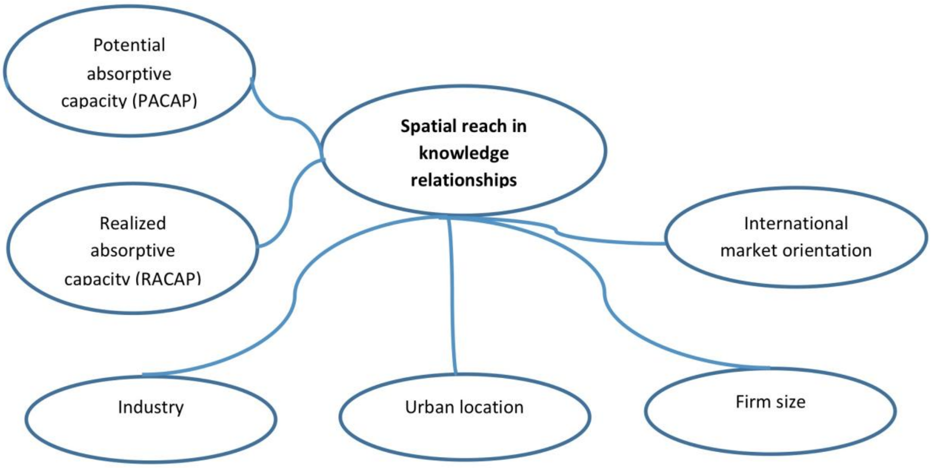

Figure 5.1. A conceptual model of spatial reach in knowledge relationships

5.2.3. Model building

Young and small firms may be subject to what is called 'liability of newness', and the associated lack of reputation and accountability often persuades them to connect with high status stakeholders nearby, at the expense of relationships elsewhere (Stinchcombe 1965; Baum and Oliver 1996; Autio et al. 2010). For this reason, the *age* and *size* of spin-off firms are included as *control variables* in our model, assuming that the older the firm and the larger its size, the more resources and capabilities it will acquire and the larger the reach in knowledge relationships may be. However, some university spin-off firms behave like 'born globals', a specific category of young firms that initiate internationalization immediately or soon after they have been founded by exporting to foreign countries and building relationships there (Madsen and Servais 1997; Andersson and Wictor 2003; Freeman et al. 2010).

Spin-off firms operate in economic sectors and industry types where the driving forces behind innovation and the associated learning processes are different. Pavitt (1984) and Tidd et al. (2005) suggest that demand-pull stimulates innovative activities in supplier-dominated, scale-intensive and specialized supplier firms, while in science-based industries, these activities are stimulated by science and technology-push. For this reason and for the need to balance the focus on resources, *industry* is included in the model as a *control variable,* with an emphasis on the difference between science-based and market-based activities. Due to the universal character of science, science-based firms tend to be globally oriented in terms of learning, except for the first stages. However, as pushed by market demand and market context, adaptive learning tends to benefit more from local face-to-face interactions in solving problems (see, also Asheim et al. 2007; Nemet 2009). This argument connects with studies suggesting that the spatial orientation in the (potential) customer market influences the reach in knowledge relationships. De Jong and Freel (2010) confirm that operating in export markets is associated with a larger reach in knowledge relationships, which is why we also include *market orientation* in our model as a *control variable*. In addition, to distinguish the influence of a different supply of knowledge in regions from that of firm-specific needs and absorptive capacity, *urban location* is included in the model as a *control variable*, as location in a metropolitan core region versus location in a remote part of Europe, with the assumption that firms in remote regions go abroad more quickly, looking for knowledge that is lacking locally (de Jong and Freel 2010).

Furthermore, the following potential absorptive capacity variables are included in the model: R&D expenditure, size of the founding team, and especially, because often neglected in potential absorptive capacity, a set of founder or team characteristics, including PhD level, multidisciplinary education, participation in training, pre-start working experience and cross-cultural experience. Realized absorptive capacity is included in the model through 'newness of innovations' and 'stage in product development'. Reasons for these selections were not only theoretical but also practical, namely availability in the given dataset, and avoiding of sources of bias (Table 5.1).

Table 5.1. Absorptive capacity, dimensions and measurement

Main category	**Dimension**	**Measurement in literature**	**This study**
Potential absorptive capacity	Knowledge acquisition	-Years of experience of R&D section (Murovec & Prodan 2009; de Jong & Freel 2010)	-No data available
		-Training (investment) of personnel related to innovative projects (Mowery & Oxley 1995; Escribano et al. 2009; Murovec & Prodan 2009)	-Business and market training/consultation
		-Share of scientists in total number of employees (Escribano et al. 2009)	-No data available
		-Fully staffed R&D department (Veugelers 1997; Escribano et al. 2009)	-Not used because not applicable for young spin-off firms
		-R&D expenditure/intensity (Nooteboom et al. 2005; Murovec & Prodan 2009; Escribano et al. 2009; de Jong & Freel 2010; Bishop et al. 2011)	-R&D expenditure
		-Continuous R&D (Bishop et al. 2011)	-No data available
		-Accumulated knowledge (Murovec & Prodan 2009; Schewns and Kabst 2009; de Jong & Freel 2010; Colombo & Grilli 2010)	-Size of founding team -Work experience of founders -PhD level in founding team - Multidisciplinary background in founding team
		-Immigrant entrepreneurship (Hart & Acs 2011)	-Origin of a founder or his/her parent(s) abroad

Potential absorptive capacity	Knowledge assimilation	-Number of cross-firm patent citation (Fabrizio 2009) -Number of citations in a firm's publications to research developed in other firms (Cockburn & Henderson 1998; Fabrizio 2009)	- No data available -Not used because only small part of the spin-off firms in this study is involved in publications
Realized absorptive capacity	Knowledge transformation	-New research projects initiated and number of new product ideas (Zara & George 2002)	- Not used because counting of new research projects and product ideas causes bias, due to different ideas about newness and a different level of detail adopted in counting
Realized absorptive capacity	Knowledge exploitation	-Number of patents (Nooteboom et al. 2005; Fabrizio 2009) -New product announcements (Zahra and George 2002) -Length of product development cycle (Keller 1996; Nooteboom et al. 2005; Gilsing and Duysters 2008) -Number of publications (Fabrizio 2009)	-Not used as a single indicator because of bias due to different patenting cultures between industries -Newness in terms of breakthrough and patent involvement - Stage in new product development (exploration or exploitation) -Not used because only small part of the spin-off firms in this study is involved in publications

5.3. Data and methods

5.3.1. Data collection

This study draws on data involving two university cities in Europe. This includes the use of a meta-analysis of the growth of 40 university-related incubators, in which the universities in Delft (Netherlands) and Trondheim (Norway) were identified as two contrasting cases (Note 1). In particular the contrast in urban location (a remote city versus a core metropolitan area) allowed to test whether the location may influence establishment of global knowledge relations. The two countries involved (the Netherlands and Norway) share a similar, somewhat risk-avoiding entrepreneurship culture (GEM 2010) and have similar scores on the main European Innovation Scoreboard indicators (ProInno Europe 2011), and both have relatively small domestic markets, making them export-orientated. This pattern makes it plausible that differences are mainly measured between the two cities and regions, and not between countries (Note 2).

Delft is a part of the Randstad metropolitan area in the Province of South Holland and the major industry in this area is commercial and service industry (Statistics Netherlands 2010), while the major industry in the Trøndelag area, where Trondheim is located, is mining, agriculture including farmed fish and processed wood, with oil and gas production as the fastest growing sector (Statistics Norway 2010). The size of the population in South Holland is 3.5 million, compared to 422.000 in Trøndelag (2010). In addition, the economy of South Holland is eight times bigger than that of Trøndelag, given a regional gross domestic product (RGDP) of 106.2 versus 12.4 thousand million Euro, indicating there are huge differences in the intensity of local/regional knowledge spill-overs and in opportunities for local networking with useful partners.

The population of spin-offs from the two universities, Delft University of Technology and the Norwegian University of Science and Technology, satisfied a number of conditions: they have all commercialized knowledge created at the universities, survived to 2006 with an age not older than 10 years and enjoyed at least one type of support from their incubation organization/university. All the firms in this population (150) were contacted by e-mail followed by an appointment for an interview. In half of the firms in Trondheim the manager of the incubator provided additional support in arranging the interviews, leading altogether to an overall response rate of 70 per cent (105 firms) (Note 3). The data were collected using a semi-structured questionnaire in personal face-to-face interviews with the principal manager, in all but three cases a member of the founding team. To analyze spatial reach in knowledge relationships, cross-section data and answers to questions about several firm characteristics during the start-up phase collected in the interviews in 2006 were used, wherever necessary supplemented via website analysis.

5.3.2. Measuring variables

Firm age was measured as the number of years since a firm was founded and firm size as the number of employees at the time the survey was conducted. Using the categorization of industry and associated learning proposed by Tidd et al. (2005), a distinction was made between two industries: 1) science-based, dealing with basics in chemistry, life-sciences, nanotechnology, etc., and 2) market-based, including specialized supplier firms providing input to complex production systems, e.g. machinery and instruments, and information processing particularly in services like finance, retailing and transport, all reflecting demand-pull learning. Furthermore, market orientation was measured as 'most important actual or envisaged customer market', using the categories regional/national and international, included in the model as a dummy variable. The final control variable (urban location) was measured in two categories as a dummy variable, Trondheim as a town in a remote and low-density region, and Delft as part of a core metropolitan area.

Table 5.1 provides an overview of the ways in which absorptive capacity was measured in literature until 2011, and how the measurement took place in the study, among other things limited to the availability of indicators in the given dataset (see, also, Table 5.2). To indicate the *potential* absorptive capacity, R&D expenditure was used as a percentage of average firm turnover over the past three years (Note 2). A small minority of the firms (15%) had no turnover because the firms did not sell their product yet, but they received substantial national research subsidies or grants from large firms (based on collaborative agreements). In those cases, income was measured using these sources. Further, the variables used to indicate amount and diversity in accumulated knowledge in the founding team were measured as follows: the number of team members, pre-start working experience in terms of the average number of working years of the first three founders, education level in terms of the number of doctorate degrees in the founding team, and multidisciplinary education, by including two classes, single discipline and multiple disciplines. Next, cross-cultural experience among the founding team members was measured by using the country of birth of the team members or their parent(s). Note that, because of limitations in the database and some doubt as to the validity of some indicators in existing literature, the years of experience of the R&D section (department) and various indicators of knowledge assimilation, were not measured (Table 5.1).

With regard to *realized* absorptive capacity, attention is first given to knowledge transformation. Indicators that are mentioned in literature were not present in the database due to the difficulty of grasping them without bias. Firstly, some respondents were reluctant to answer questions on new research projects and new product ideas for reasons of secrecy, and secondly, counting new product ideas would have allowed bias to enter, because the result would depend on the level of detail provided by the respondent (Zahra and George 2002). With regard to knowledge exploitation, certain aspects of the indicators mentioned in literature were included in two variables, i.e. newness of the innovation and stage in new product development in the firm. Newness was measured in three categories, based on whether the product was perceived as a breakthrough and/or new to the sector, and on whether patent(s) were involved. Simply counting the number of patents was avoided, for the reason mentioned that different sectors have different patenting cultures (Kleinknecht et al. 2001; Mann and Sager 2007). Furthermore, the stage of new product development was measured as a rank variable with two categories: early development, including pilot and testing, and the later stages, including market introduction and related consultancy.

The dependent variable in this study (spatial reach in knowledge relationships) was measured as an ordinal variable indicating the scale of reach in three ranks: (1) no international knowledge relationships, (2) only Europe, (3) Worldwide. The data were collected by asking the respondents about which sources of knowledge they felt had been important to the growth of their firm. It was not possible to reach the level of detail of cities because many firms were reluctant to mention a city as information that is apparently highly sensitive. In measuring spatial reach on the level of countries and continents, we captured physical distance in a way which is important because at a larger distance new partners in the upcoming BRIC countries and Korea can be reached, aside from the US.

5.3.3. Ordered regression analysis

To understand the spatial distribution of phenomena, usually spatial analysis or spatial network analysis are used (e.g. Maggioni et al. 2007), which measure the phenomena as points in space. However, as indicated previously, this level of detail (cities) was not available in the dataset, reason why attention focused on regression analysis. Because we could not use OLS (Ordinary Least Squares) analysis, since the distances between adjacent spatial levels were unknown for the dependent variable (spatial reach), we used Ordered Logistic regression, based on the assumption that the levels of spatial scale had a natural ordering. Ordered logistic regression uses maximum likelihood estimation as an iterative process**.** Ordinal probit regression analysis could also have been used, which produces outcomes that are similar to the ones from ordinal logistic regression.

The common checks and considerations were performed, namely, a check for multi-collinearity and inspection of the endogeneity issue, Thus, correlations between the independent variables were examined to check for multi-collinearity (Appendix 1). The strongest single correlation was between firm age and firm size (0.58), and there was also strong correlation between firm age and stage of new product/process development (0.56) and a strong negative correlation between firm age and R&D spending (-0.47), referring to lower R&D expenditure among older firms, which underpinned the decision to exclude firm age from further analysis. This step did not result in omitted variable bias, due to its very weak correlation with the dependent variable (see Appendix 1). The remaining correlations (below 0.50) did not indicate serious concern for multicollinearity (Hair et al. 1995).

Next, the endogeneity issue was investigated. While potential absorptive capacity was measured mainly in terms of team characteristics at the time of the start, a couple of years ago before the survey, including founding team size, pre-start working experience, education of founding team members (PhD level), the dependent variable was measured as the situation of firms at the time of survey (2006), thus excluding reverse causality and simultaneous bias. However, four other independent variables included in our model were tested for endogeneity: R&D expenditure, market orientation, participation in training and level of newness. For example, spatial reach in knowledge relationships could enhance the level of newness or could cause a firm to increase its investments in (market) training. As a result of the analysis, all four variables were found to be exogenous. We tested the endogeneity of international knowledge relationships taking four explanatory variables in the model. These variables were R&D expenditure, market orientation, participation in training and newness. First, using two stage conditional maximum likelihood (2SCML) suggested by Alvarez and Glasgow (1999) to deal with endogenous dichotomous variable X (international knowledge relationships) and continuous explanatory variable (R&D expenditure), R&D expenditure was found not to be endogeneous. Second, we used probit model for endogenous regressors in STATA to test for endogeneity while both endogenous variable and explanatory variables were dichotomous. Using IV Wald test of exogeneity, first we assumed that variable X (international knowledge relationships) was endogenous, and we accounted for it using variable Z (market orientation) (Rivers & Vuong, 1988; Wooldridge, 2002). Next, we assumed that variable X (international knowledge relationships) was endogenous, and we accounted for it by using variable Z (newness). Wald Test checked whether X was endogenous or not, on the basis of whether the error terms in the structural equation and the reduced-form equation for the endogenous variable were correlated. The outcome of the first test $Chi^2(1)= 5.99$ (Prob > $Chi^2= 0.014$) and second test $Chi^2(1)= 3.30$ (Prob > $Chi^2= 0.069$) confirmed that 'market orientation' and 'newness' were exogenous. In the same way, endogeneity of variable X (international knowledge relationships) was checked, instrumenting for variable Z (business and market training). The outcome of the first test $Chi^2(1)= 3.07$ (Prob > $Chi^2= 0.079$) confirmed that 'participation in training' was exogenous. The previous tests were performed for a binary variable 'international knowledge relationships' (Taheri and van Geenhuizen 2011). Due to a high correlation between this variable and spatial reach in knowledge relationships (0.90), we expected that the negative results of the endogeneity test for international knowledge relations also holds true for spatial reach in knowledge relationships, confirmed that R&D expenditure, market orientation, participation in training and newness were not endogenous in the model.

5.4. Results

5.4.1. Descriptive statistics

On average, the spin-off firms in the sample were 5 years, and had a size of almost 7.5 full time equivalent (fte) (Table 5.2). Around 40% of the sample were located in a remote region (Trondheim) and 60 per cent in a core-metropolitan area (Delft). Spin-offs in science-based industry were in a minority (27%), with most firms engaged in market-based activities (73%). In addition, there were more service firms than manufacturing firms in the sample (57% versus 43%). The science-based firms were mainly in the chemical sector, optical products and other manufacturing (new materials). With regard to differences in sectors between Delft and Trondheim, we observed a larger share of manufacturing of machinery and equipment in Trondheim compared to Delft (25% versus 13%) (Appendix 2). The firms in Trondheim in this sector were involved with the energy sector e.g. new turbines, linear motors, windmill components and drilling equipment. Also, Trondheim, compared to Delft, had a somewhat larger service sector (61% versus 54%) which was mostly involved in informatics, communication and professional and technical activities in the energy sector. Furthermore, with regard to market orientation, a majority of the firms in the sample (64%) adopted an international orientation. The spin-off firms examined spent on average 40% of their revenues on R&D (Table 5.2). A minority (32%) of the spin-offs were founded by a single entrepreneur, while most spin-offs (68%) were founded by two or more entrepreneurs. Most spin-offs only had a technical background in one area (66%), while a minority (34%) had a background in more than one technology or a combination of technology and other areas, for instance management. In addition, most founders did not have a PhD (62%), although a minority did (38%). Participation in market and business-related training/consultation was found among a small part of the spin-offs (31%). Few founding teams had a cross-cultural background (15%), which is why we removed cross-cultural experience from the model analysis.

About 42% of the firms were involved in very new, breakthrough and/or new to the sector product development, with protection by patents (Table 5.2). A smaller part was involved in inventions that are new at a medium level and without patent protection (35%), in most cases involving software/hardware applications. The remaining firms (23%) were characterized by a low level of newness and were mainly active in less advanced software or engineering projects with established positions in customer markets. Most spin-offs (63%) had introduced their product into the market or were active in related consultancy services. A minority (37%) was still in the early development stage or pilot production and subsequent testing, and had not yet marketed their inventions.

A majority of the spin-off firms in the database (62%) engaged in international knowledge relationships (Table 5.3), often over large distances, with the spin-offs active outside of Europe outnumbering the ones merely active within Europe (33.5% versus 28.5%). These results show a different pattern compared to the findings by de Jong and Freel (2010), in which 78% of the network partners are in the home country (Netherlands) and the rest abroad, both inside and outside Europe. This different pattern, 38.0% of the firms in the current study had their knowledge relationships in the home country, may be caused, first of all, by the decision in the current study to focus specifically on university spin-off firms, namely, while the other study looks at a broader category of high-technology SMEs, and, secondly, by the type of knowledge relationship, where the relatively limited sourcing activity in the current study contrasts with the more comprehensive approach adopted in the other study.

Cultural distance could not be measured in this study but it is plausible that worldwide active spin-offs excluding North America (about 30%) have crossed substantial cultural barriers, like with Latin America, Africa and Asia. The spin-offs in the sample that employ worldwide knowledge relationships were mostly at product/service sales stage and had developed knowledge relationships with customers, while a smaller group was working, on site, in foreign countries on a project basis, including civil engineering works and construction in the oil sector, tailoring their activities to meet the needs of local customers. The relatively large segment of spin-offs that was already present in the market (64%) indicates that market-related sources, mainly customers and suppliers, were the most important source of knowledge relationships (41%), with annual exhibitions/fairs coming in second place (23%). Knowledge acquisition from universities and research institutes occurred less often internationally (6%).

Table 5.2. Descriptive statistics

Variable	
N university spin-offs	105
Spatial reach in knowledge relationships a)	Not internationalized (38.0%) Merely within Europe (28.5%) Worldwide (33.5%)
Control variables	
Industry- science-based (dummy)	Science-based: 26.7% Market-based: 73.3%
Firm size (employees)	Average: 7.4; s.d.: 7.06; Min-max: 0.5-51
Firm age	Average: 5.1; s.d.: 3.03; Min-max: 0-10
Market orientation (dummy)	Regional/national: 36.2% International: 63.8%
Urban location (dummy)	Remote (41.0%) Core metropolitan (59.0%)
PACAP	
R&D expenditure (%)	Average: 39.8; s.d.: 23.07; Min-max : 0-100
Working experience of founding team (years)	Average: 2.6; s.d.: 4.05; Min-max: 0-21
PhD level in founding team	Average: 0.6; s.d.: 0.86; Min-max: 0-3
Size of founding team	Average: 2.3; s.d.: 1.16; Min-max: 1-5
Multidisciplinary education of founding team	Single discipline (65.7%) Multiple discipline (34.3%)
Participation in training (dummy)	Yes (31.4%) No (68.6%)
Cross-cultural experience (dummy) b)	Yes (15.2%) No (82.8%)
RACAP	
Newness	Low level (22.8%) Medium level without patents (35.2%) High level with patents (42.0%)
Stage in product development	Development/pilot/testing: 37.2% Introduced to market: 62.8%

a. In the modelling part, aggregation to three was necessary for statistical reasons.
b. Missing data: 2%

Table 5.3. Spatial reach in knowledge relationships

Spatial reach	N	Percentage
Not internationalized	40	38.0
Internationalized	65	62.0
- Merely Europe	30	28.5
- North America	4	3.9
- Asia	2	1.9
- Various continents	29	27.7
Total	105	100

5.4.2. Analysis

Spatial reach in knowledge relationships was examined in three classes: not internationalized, internationalized merely within Europe and internationalized worldwide, and a stepwise regression analysis was conducted by adding various new variables to the model at each step. Model 1 includes four control variables that leads to a rather weak result (Pseudo R^2 of 0.10) (Table 5.4). All four coefficients, industry (science-based activity), firm size, market orientation and location in a remote region, are found to be positive and significant. Next, six variables are added to the model, representing potential absorptive capacity, which increases the model power by 0.05 in Model 2. In Model 3, three variables representing realized absorptive capacity are added to the control variables, which causes the model power to increase by 0.02 (compared to Model 1). Next, by including all the variables in Model 4, a Pseudo R^2 of 0.17 is reached. The coefficients PhD education, participation in training and newness (low level) are positive and significant. In a final step, various interaction terms are explored within the model to see whether they increase the model power, which found to be only true for the interaction term of location and participation in training (Model 5). Accordingly, the model improves to an R^2 of 0.19. The interaction effect can be understood as follows. Spin-off firms with a higher absorptive capacity through training/consultation while facing shortage in knowledge in their city/region tend to bridge larger distances to acquire new knowledge.

The above results confirm a positive and significant influence of international experience, through PhD studies, on the spatial reach of knowledge relationships, which is partly in line with Colombo and Grilli (2010), who observed that the number of years of university education of the founding team members,- thus on a lower level - mainly in economics and management, has a direct and positive impact on firm performance as a broader outcome. The results also match a broader observation with regard to higher education as a characteristic of high-technology entrepreneurs or teams being linked to a higher level of international openness (Cavusgil 1984; Lane et al. 2001; Liu 2012). In other studies, the knowledge and skills of the founding team are also found to be closely related to firm capabilities as a basis for performance (Feeser and Willard 1990; Colombo and Grilli 2005). In addition, the positive role of participation in training on spatial reach can be understood given the lack of market knowledge in most spin-off teams (van Geenhuizen and Soetanto 2009). A positive influence of training on a firm's ability to recognize and exploit knowledge opportunities worldwide is confirmed in other studies, for instance Murovec and Prodan (2009) and Escribano et al. (2009).

The urban location of the spin-offs also found to be a significant factor: firms in relatively small cities in remote regions, such as Trondheim, are more likely to bridge larger distances in acquiring knowledge from abroad than firms in a core metropolitan area (Delft). Following Feldman (1994) and de Jong and Freel (2010), distant collaboration tends to be a response to resource deficiencies in the local/regional area, in this case, a remote non-metropolitan location in Norway urges the firms to look further, often outside Scandinavia. However, this may also be due to the inherent international orientation of the energy sector, which has a strong presence in the Trondheim region. Although the aim was to exclude national differences in terms of innovation systems, size of the economy, etc., by comparing Norway and the Netherlands, there is one factor we did not take into account and may have contributed to the significant result of location in a remote region, and that is a different perception of distance between the two countries, leading to a different network building behavior, with a willingness to travel over larger distance in the larger of the two countries (Norway).

Furthermore, science-based firms are found to be more likely to cross larger geographical distances to establish knowledge relationships, which is in line with the spatial dimension connected to the learning concepts posed by Asheim et al. (2007). Accordingly, science-based firms tend to be globally oriented in their knowledge acquisition due to the universal character of science, while adaptive learning pushed by demand and market context tends to benefit more from local face-to-face interaction. Moreover, larger firms in the sample are found to be more likely to establish distant knowledge relationships, probably due to the loosening of ties of growing firms with their territories (Torré 2008) and an increase in the financial and human resources as firms grow.

With regard to realized absorptive capacity, the coefficient of low newness is positive and significant. This surprising result can be described as follows. The majority of the firms engaged in low levels of newness (n = 23) was active in market-oriented sectors, mostly in later stages of development. Accordingly, they had already established market positions and participated in knowledge relationships abroad through market-based sources in the shape of customers and suppliers in different countries worldwide.

Overall, seven variables found out to be important. Spin-off firms in Trondheim, larger firms, firms in science-based industry, firms with an international market orientation, firms with PhD experience, firms participating in training, and firms with a relatively low level of newness are all likely to acquire knowledge over larger geographical distances (Table 5.4). In addition, there is a strong dependency on the part of spatial reach on three absorptive capacity indicators, namely, PhD experience, participation in training and low levels of newness.

Contrary to expectations, the coefficients of R&D expenditure, size of founding team and multidisciplinary education in this team are negative and non-significant. Different from de Jong and Freel (2010), R&D expenditure is not sufficient to reflect the firms' internal capacities to build distant knowledge relationships. Continuity of R&D activities may provide a better indication of a firm's engagement in R&D, enabling that firm to establish distant knowledge relationships, as found by Xia and Roper (2008) and Bishop et al. (2011). A negative impact of team size at the start may be described by the strategy of larger teams first to exploit all in-house knowledge before looking elsewhere. A second explanation could be the increase of the chance of ‘social loafing’ among larger teams, whereby members exert less effort and perform at lower scales if working in a group compared to working alone (McShane and Travaglione 2007; Robbins and Judge 2011), leading to a reduced effort in building networks. In this study, no influence of previous working experience on establishing knowledge relationships abroad is found that is in line with the study by Fletcher and Harris (2012) who observe that small firms do not rely on experiences available in their team but acquire indirect experience through external partners, namely, government advisors and consultants as a source of internationalization knowledge and increase firm absorptive capacity indirectly. However, a recent study by Liu (2012), in contrast to this study, finds that absorptive capacity accumulated through prior knowledge and experience is significantly associated with cross-border learning.

Finally, a negative influence of multidisciplinary education may be described by the impact of heterogeneity among team members. While heterogeneity may cause synergies in a team, it may also reduce team cohesion and create dissonance and conflicts among team members, which will have a negative effect on firm processes, including building networks (Pelled 1996; Horwitz 2005; Shrivastava and Tamvada 2011).

Table 5.4. Ordered logistic regression analysis of spatial reach in knowledge relationships

Variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Control variables	Ologit coef.(s.e.)	Ologit coef.(s.e.)	Ologit coef.(s.e.)	Ologit coef.(s.e.)	Ologit coef.(s.e.)
Industry- science-based (yes=1)	1.25 (0.47) ***	1.48 (0.51) †	1.38 (0.50) ***	1.57 (0.53) †	1.63 (0.54) †
Log firm size	0.58 (0.24) **	0.78 (0.29) ***	0.51 (0.25) **	0.75 (0.31) **	0.77 (0.32) **
(International) market orientation (yes=1)	0.85 (0.43) **	0.74 (0.46)	0.98 (0.47) **	0.83 (0.50) *	0.77 (0.50)
Urban location (Trondheim=1)	0.73 (0.40) *	1.05 (0.47) **	1.03 (0.43) **	1.28 (0.49) ***	0.87 (0.54)
PACAP					
R&D expenditure	-	-0.08 (0.10)	-	-0.05 (0.11)	-0.03 (0.11)
Working experience of founding team	-	0.00 (0.19)	-	0.01 (0.20)	0.09 (0.20)
PhD level in founding team	-	0.83 (0.37) **	-	0.82 (0.39) **	0.78 (0.39) **
Size of founding team		-0.29 (0.18)	-	-0.29 (0.18)	-0.28 (0.19)
Multidisciplinary education of founding team (yes=1)	-	-0.42 (0.47)	-	-0.39 (0.48)	-0.56 (0.50)
Participation in training (yes=1)		0.84 (0.48)*	-	0.95 (0.49)*	0.55 (0.55)
RACAP					
Newness- low level (dummy)	-	-	1.12 (0.57) *	1.23 (0.60) **	1.49 (0.63) **
Newness- high level (dummy)		-	0.69 (0.48)	0.65 (0.52)	0.84 (0.54)
Stage in product/process development	-	-	0.42 (0.44)	0.02 (0.7	0.01 (0.48)
Urban location* Participation in training	-	-	-	-	1.95 (1.11)*
N	104	104	104	104	104
LR Chi square	22.15†	33.80 †	27.29 †	38.37 †	41.58 †
Pseudo R^2	0.10	0.15	0.12	0.17	0.19
Change in Pseudo R^2					0.014
Log likelihood	-100.53	-94.71	-97.96	-92.42	-90.81

* P<0.1, ** P<0.05, *** P<0.01, †P<0.005

5.5. Discussion and conclusions

Extending knowledge collaboration over larger distances is increasingly compelling for university spin-off firms in Europe. Aside from the US and Japan with established positions in the global landscape of innovation, other countries are emerging as centres of R&D and innovation, like China, India, Korea and Brazil. As resource-based views suggest, however, spin-off firms have different needs for new competitive knowledge and ‘invest’ different amounts of absorptive capacity in their search of new knowledge. Most spin-offs in this study (62%) were found to be engaged in international knowledge acquisition, mainly across larger distances (34%), with customers as the most important category of knowledge sources, but there are clear reasons for the differences in knowledge acquisition abroad.

These reasons were explored using two sets of factors: a set of absorptive capacity indicators that encompass potential absorptive capacity and realized absorptive capacity, and a set of firm-related factors, including urban location. Using ordered logistic regression in testing the model on 105 firms in Norway and the Netherlands, seven important factors were identified, which, in terms of absorptive capacity indicators, included PhD education, participation in training, and a low level of newness, and in terms of firm-related factors used as control variables, included firm location in remote regions, firm size, firm industry as science-based activity, and international market orientation.

To date, a small number of studies on innovative SMEs (as a broader category) deals with spatial patterns of knowledge relationships (e.g., de Jong and Freel 2010; Laursen and Salter 2004). In both studies, the focus is on R&D factors covering one dimension of potential absorptive capacity, aside from some structural firm characteristics. Furthermore, the attention in research for knowledge collaboration by SMEs is increasing today but mostly in terms of impacts or benefits gained by the knowledge relationships (e.g. Bishop et al. 2012).

Accordingly, this chapter is different and extends the literature in four important ways. First, it adds to the insights on the role of absorptive capacity in spatial reach of firms in knowledge networking in the framework of an increasing need to cross larger distances to connect with new players in innovation like Brazil, South Korea, and China, which has only recently been included in research agenda's. Absorptive capacity is a key in learning processes of firms and in the ultimate exploitation of external knowledge, leading to different outcomes in innovation and use of networks abroad. Such differences have been neglected in studies that put the agglomeration advantages of large cities, or physical proximity, in the first place. Secondly, we used a more comprehensive measurement of absorptive capacity by extending the scope which has often been limited to R&D indicators, with various individual quality factors of founders or founding teams potentially enabling enlarging the spatial reach, namely, experience and education/training, which found to be significant in the model results. Thirdly, the absorptive capacity of the focal category of firms in this paper, university spin-offs, has not yet been studied. The results complied with studies of a broader category of firms (innovative SMEs) as far as the influence of the firm size, science-based activity and international orientation are concerned (de Jong and Freel 2010). The results, however, 'challenged' the influence of the level of newness of innovations, as apparently low levels of newness are associated with a large amount of absorptive capacity in knowledge relationships, which could be caused by the fact that these firms in our sample were often active in oil (energy) production, improving utilities, and engineering and software projects on site abroad, and that they were likely to establish international knowledge relationships with customers/partners due to a relatively short time-to-market. Fourthly, while urban location was a significant factor in spatial reach in knowledge acquisition and we thus could confirm a wider reach among spin-off firms in remote regions, as found by de Jong and Freel (2010), we had to draw attention to the regional economy, with the influence of highly globalized sectors like the energy sector in remote regions, and to a potentially higher willingness to cross large distances in countries that are large in size, all potentially part of the explanation.

Using the resource-based view of firms increased understanding of a different reach in internationalization, as some of the identified factors act as enabling factors (availability of resources needed to ‘invest’ in internationalization tasks, partly to overcome various barriers) while others act as factors that define the need for unique resources (knowledge) to be gained through internationalization. Both countries in the study, the Netherlands and Norway, share a somewhat risk-avoiding entrepreneurial culture in a small and open national economy, and specialize in new technology in seashore activities, mainly transport and energy, which indicates that the results may have implications for technical universities in only a limited number of similar countries, such as Denmark, Sweden and northern parts of the United Kingdom, also taking the role of willingness to cross large distances into account.

The modelling results were the first of its kind in covering a relatively broad range of absorptive capacity indicators, including both potential and realized absorptive capacity, as distinguished by Zahra and George (2002). Good results were gained on three of the eight indicators, while the overall power of the models remained relatively weak, albeit comparable to similar studies (see Note 4), which supports the finding that absorptive capacity works differently under diverse circumstances, while it is also difficult to measure in a direct way (Zahra and George 2002; Murovec and Prodan 2009; Schmidt 2010). The explanatory power of the presented models, however, may be increased by examining several variables in greater detail, namely, working experience of the founding team (Schewns and Kabst 2009). In particular, more attention may be paid to the dynamics within the founding team, with different sizes and with heterogeneity in terms of the disciplines. Also, attempts could be made to move from using proxies in measurement to more direct measures of absorptive capacity and other, as yet unidentified, indicators of absorptive capacity could be included, for instance knowledge assimilation indicators.

Going one step further in the analysis, it was found that global knowledge relationships tend to positively influence the growth of spin-offs in terms of turnover and employment, especially in an innovative sample of spin-off firms that is beyond the scope of this paper (Note 5). However, this result may have practical implications. As an advice aimed at enhancing knowledge relationships abroad and accelerating firm growth, mainly addressed at the management of incubators and/or universities, it can be recommended that founding teams include members holding a PhD, since their experience in crossing borders enables them to operate in international networks and overcome particular barriers more quickly. Moreover, the data set revealed a diverse level of innovativeness among spin-off firms (less innovative ones with established market positions versus highly innovative ones that are still in the development stage) and managers of incubation centres should tailor specific programs and support for such different types of spin-off. In addition, it can also be recommended to provide spin-off firms with training in specific skills to further support them in reaching global knowledge sourcing if needed.

Note 1

Using data on university-related incubators in various countries, 40 incubators were selected representing particular growth patterns. It was found that two factors determine growth of incubators, i.e. stakeholder involvement in managing the incubator and level of urbanization of the location (Soetanto and van Geenhuizen 2007). Next, using a framework to select two incubators with contrasting positions with regard to these factors NTNU Trondheim in Norway and TU Delft in Netherlands were selected.

Note 2

We checked for significant differences in accounting systems between the Netherlands and Norway, but we found a harmonized accounting legislation for small enterprises in the European Union and this holds true for non-listed limited liability companies, which is the legal status of most spin-off firms (EC 2011).

Note 3

A previous study found that around 80% of the spin-offs in Delft managed to survive the first ten years. Using simulation studies, it appeared that firms that have failed in this period do not differ significantly from the ones that survived (van Geenhuizen and Soetanto, 2009) which is the reason why major selection bias in the results from not-surviving can be excluded.

Note 4

De Jong and Freel (2010), using multilevel regression model to describe reach of collaboration in high technology small firms, do not reach a Pseudo R^2 higher than 0.20. Escribano et al. (2009), using a logit model to describe managing knowledge flow and innovative outcomes, reach a R^2 of 0.19 in their best model, and Murovec and Prodan (2009), using structural equations to measure innovation output, do not reach a R^2 higher than 0.25.

Note 5

Using a growth model, spin-off firms' turnover and employment growth were studied since foundation to 2010. It is observed that firm's international knowledge relationships as measured in 2006 had a positive and significant influence on firm average employment growth and firm turnover growth since foundation. More details on the relevant models are presented in Chapter 7 of this book.

Appendix 1

Table 5.5. Correlation matrix (n=105) a)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 International knowledge relationships	1																
2 Spatial reach in knowledge relationships	0.90	1															
3 Firm age	0.05	0.08	1														
4 Urban location	-0.04	-0.15	0.24	1													
5 Firm size	0.05	0.16	0.58 **	0.14	1												
6 Market-orientation	0.28 **	0.30 **	-0.06	-0.17	0.12	1											
7 Industry - science-based	0.24 *	0.27 **	-0.32 **	-0.08	-0.30 **	0.22	1										
8 Cross-cultural experience	-0.05	-0.05	-0.17	-0.02	-0.16	0.04	0.05	1									
9 R&D expenditure	0.16	0.07	-0.47 **	-0.16	-0.23 **	0.28 **	0.31 **	0.17	1								
10 Work experience of founding team	0.20 *	0.19	0.03	-0.33 **	-0.13	0.21	0.17	0.17	0.19 *	1							
11 Size of founding team	-0.15	-0.09	-0.15	-0.06	0.26 **	-0.04	-0.08	-0.09	0.02	-0.27 **	1						
12 PhD level in founding team	0.25 **	0.29 **	-0.10	-0.17	-0.14	0.31 **	0.22 *	0.20 *	0.17	0.42 **	-0.14	1					
13 Multidisciplinary education of founding team	0.04	0.11	0.01	-0.17	0.38 **	0.14	0.05	0.03	0.06	0.01	0.20 *	0.03	1				
14 Newness - high	0.26 **	0.21 *	-0.24 **	0.02	-0.03	0.39 **	0.30 **	0.12	0.45 **	0.09	-0.04	0.31 **	0.03	1			
15 Newness - low	0.00	-0.03	0.32 **	0.23 *	0.13	-0.35 **	-0.28 **	-0.04	-0.43 **	-0.19	0.04	-0.25 *	-0.10	-0.47 **	1		
16 Participation in training	0.07	0.10	0.10	-0.20 *	0.33 **	-0.10	-0.13	-0.01	-0.16	-0.29 **	0.10	-0.21 *	0.17	-0.01	-0.12	1	
17 Stage in new product development	0.05	0.06	0.56 **	0.21 *	0.37 **	-0.13	-0.20 *	0.01	-0.35 **	-0.04	-0.09	0.00	0.09	-0.12 **	0.17	0.17	1

*P<0.05, **P<0.01, a) Spearman correlation coefficients.

Appendix 2

The firms were mainly involved in service activities (57%), while 43% of firms were active in manufacturing.

Table 5.6. Sectoral breakdown of firms in the database (NACE)

Sector	**Delft**	**Trondheim**
Manufacturing:	*28(45.9%)*	*17(38.6%)*
Machinery and equipment	13.1%	25.0%
Computer, electronic, optical products and electrical equipment	11.5%	6.7%
Chemicals, chemical products, basic pharmaceuticals, etc.	11.5%	4.6%
Other manufacturing	9.8%	2.3%
Services:	*33(54.1%)*	*27(61.4%)*
Information and communication	31.2%	38.7%
Professional, scientific and technical activities	22.9%	22.7%
Total	*61(100%)*	*44(100%)*

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How Absorptive Capacity Through Education and Experience of Founders Influences Firms' Openness[*]

Abstract

Open innovation is well conceptualized and researched for large established firms, but not for small and young ones. This situation holds particularly for the question why some firms are more open in knowledge networks and others more closed. Having open relations can be seen as a prerequisite for open innovation practices. This chapter fills the gap on small firms, by an analysis of openness using two dimensions, namely, size of the knowledge pool (openness capacity) and diversity in the partners involved (openness diversity), and a rich set of underlying data. Important *positive* influences on one or two openness dimensions tend to be: firm size and founding team size, experience of the founding team and multi-disciplinary in their education, and as an indicator for strategy, being involved in innovation as prospector. Competition in the market tends to stimulate openness in knowledge networks. With regard to the influence of cities, regional location tends to make a difference too, with a location in a remote region stimulating openness in networks, particularly in search for diverse partners.

6.1. Introduction

Like the previous chapter, this chapter is concerned with a main characteristic of knowledge networks of spin-off firms, i.e. the level of openness, considered within the framework of open innovation. Similar to internationalization, spin-off firms tend to face a *dilemma* in this respect, namely, between the need to 'capture' external resources through open relationships in order to sustain innovation and growth, and the limited resources and capacity owned by the firm and necessary in building and managing such open relationships.

The practice of innovation by firms has experienced major changes since the 1990s. The source of successful innovation has gone beyond being productive in R&D, through improving management practices and delivery of new, high quality products and processes to market. Innovation is not solely dependent on discovery of scientific knowledge or formal R&D activities; instead, it has become the result of various interactive processes through involving a wide range of parties, like suppliers, customers, competitors, universities, venture capitalists, and government

[*] A first version of this chapter was published in 2013 as a chapter of a book (Ye et al. 2013). A later version of the chapter was submitted to the journal R&D Management in December 2012 and is now in revision. First author is M. Taheri, and co-authors are Qing Ye who did part of the analysis as thesis work (MSc) (Ye 2012) and Marina van Geenhuizen as supervisor. We thank two referees of R&D Management for their constructive comments to the paper. Propositions 2.2 and 4.2 dealing with the subject matter of this chapter are forwarded in Chapter 2, are not tested in the current chapter, but in Chapter 8 among an overall reflection on propositions.

agencies (Chesbrough 2003; Leiponen 2005; Chesbrough et al. 2006; Laursen and Saulter 2006; Love et al. 2011). In particular, customers are playing an important role in firms' learning processes by getting involved much earlier than before, thereby shortening time-to-market and reducing market uncertainty (von Hippel 2005; Thomke and von Hippel 2002).

The previous trends have been popularized through the concept of open innovation, defined as the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation respectively (Chesbrough 2003). There is an 'outside-in' element meaning that innovation in the firm benefits from external inputs, whereas the 'inside-out' element refers to outputs of the firm into other organizations, often market oriented. The simultaneous combination of the two is a third option, and is named co-creation and can be seen as an advanced collaboration (Enkel et al. 2009).

Opening up the innovation process is not just about giving up control and hoping for the best, it is about implementing mechanisms to govern, shape, maintain and, if necessary, constrain the input from external innovators. Thus, successful firms are those that invest in effective knowledge relationships with suppliers, sub-contractors, knowledge-intensive firms, experts/advisors, universities and research institutes, using a strategic selection and selective maintenance of such knowledge relationships, and thus may show different kinds and levels of openness (Hughes et al. 2007; Mansury and Love 2008; Boudreau and Lakhani 2009; Belussi et al. 2010; Dahlander and Gann 2010).

In this chapter, openness in relationships is seen as a major requirement for open innovation, but it is not always the same. Open innovation goes deeper than just involving others in idea generation or retrieving knowledge from others, the contribution from outside is clearly significant and arranged on purpose. It also goes further than a partnership in which the firm pays for particular services. Partners in open innovation processes focus on problems, needs and issues, while typically *working together* (Lindegaard 2011). At the same time, openness in knowledge relations is broader than innovation in the sense of new products, processes and methods; it also includes marketing and management, and ways of financing.

The literature indicates that openness is increasingly studied as an important influence on firm innovation and firm performance (e.g., Deshpande and Farley 2004; Laursen and Salter 2006; Leiponen and Helfat 2010; Fu 2012), but causes of differentiation in openness have rarely been revealed, except for a few recent studies (Barge-Gil 2010; Drechsler and Natter 2012). Some researchers have put an emphasis on environmental factors influencing openness, like market turbulence (Chesbrough 2007), while others argue that the internal resources situation, namely, indicating internal weaknesses and impediments to innovation, is more important in taking an open strategy (Keupp and Gassmann 2009; Barge-Gil 2010). In contrast, Drechsler and Natter (2012) forward importance of both, while observing the use of a closed model of innovation among firms lacking important expertise that prevents them to identify potential collaboration partners, and also among firms that are facing serious competitive threats and high risks of imitation. However, the previous studies are still limited in a way, taking up openness as one dimensional.

In the past two decades, knowledge transfer from universities has received an increased attention with spin-off firms as one of the most important and visible channels (e.g. Shane 2004; Debackere and Veugelers 2005; Djokovic and Souitaris 2008; Huggins and Johnston 2009). Several empirical studies show, however, that most spin-off firms perform rather poor in employment growth (e.g. Mustar et al. 2008). Being created for the purpose of commercially exploiting knowledge or research results developed within a university or research institute (Pirnay et al. 2003), the entrepreneur is often a graduate or a university staff member and these are usually faced with a lack of resources, particularly market and marketing knowledge (van Geenhuizen and Soetanto 2009). With regard to openness in knowledge relationships, this situation causes a *dilemma*: while spin-off firms need various inputs from other firms and organizations, they lack resources that enable searching, building and maintaining networks and benefiting from this input (Dahlander and Gann 2010).

It needs to be mentioned that university spin-off firms are to a certain extent heterogeneous, starting as a firm with different capabilities and resources - as evidenced for example by differently composed founding teams (Druilhe and Garnsey 2004; Heirman and Clarysse 2004; Colombo and Grilli 2010). They also develop different strategies in grasping opportunities, causing diverse needs for openness in knowledge collaboration (Andersson 2008; Mohr et al. 2010). Such heterogeneity of spin-off firms connects with theoretical ideas of Teece (2007) enabling to view openness as a dynamic capability that is built and used on the basis of various learning processes (Zahra et al. 2006). From the previous arguments it follows that openness in knowledge relationships is not being adopted by all spin-off firms to the same extent and also not in the same way. They face different needs for the benefits of openness, and they have different resources and capabilities at their disposal to develop openness.

Against this background, this chapter aims to describe differences in openness between spin-off firms form the viewpoint of the ‘resources dilemma’, different enabling internal factors and different strategies. The research question is as follows: What is the pattern of openness in networking among spin-off firms and what drives these firms to make their networks more open?

This chapter contributes to the empirical literature as follows. First, given the almost neglect of small firms in open innovation research, except for van de

Vrande et al. (2009), Gassmann et al. (2010) and Hayter (2010), it presents results on a specific category of small firms, namely university spin-off firms, which are facing the dilemma of a strong need for external resources but lack of internal resources that enable to increase openness. Second, as preceding studies focus on the influence of openness on innovation or performance, the current study casts light on openness itself and on why spin-offs are different in openness, drawing on diverse enabling factors (connected with resources), strategy factors and the external environment. Third, given a lack of understanding of what openness constitutes in terms of main components, the focus in this chapter, drawing on Laursen and Salter (2006), is on breadth and depth of the external knowledge pool including knowledge domains, and additionally on diversity in a socio-economic sense between the knowledge partners involved. Accordingly, given a limited coverage in measurement of openness in the literature (Barge-Gil 2010; Drechsler and Natter 2012), in the quantitative approach in this chapter, a rich measurement of openness is applied.

A sample of 105 university spin-off firms is studied and the results unfold as follows. In section 6.2, theoretical perspectives and the model design are discussed. Data, methodology and description of the sample including spin-off firms' openness are addressed in section 6.3 and 6.4. This is followed by a discussion of the results of multiple regression analysis in an attempt to clarify the differentiation in openness using multivariate modeling in section 6.5. The last section closes with an evaluation of the results and a brief indication of policy implications.

6.2. Theory and model building

The focus on openness and interaction reflects a wider trend in studies of firm behavior suggesting that the network of relationships between the firms and their external environment can play a decisive role in shaping performance, for example in innovative output (Powell et al. 1996). Openness can be conceptualized as the ability and willingness of a firm to make use of a wide range of external knowledge sources (Laursen and Salter 2006). In the current study, it is seen as the actual result of searching efforts and network building, and as one of the preconditions for open innovation. Openness does not tell about the collaborative effort involved in the knowledge gaining, meaning that openness, as conceptualized in this chapter, is only partly related to open innovation.

The current study has a focus on inbound openness based on the observation in the literature that there are only few knowledge exploitation (inside-out) activities conducted by SMEs, particularly the smaller ones (van de Vrande et al. 2009), but there are indications for a more varied pattern of open relationships, including co-creation of spin-off firms with large customers.

In the current study, conceptual ideas are developed using two dimensions of openness among spin-off firms: size of the outside knowledge pool in terms of breadth and depth thereby differentiating between knowledge domains, named openness capacity, and diversity in the sources of knowledge used, named openness diversity, differentiating between socio-economic circles of the partners involved (Laursen and Salter 2006; Leiponen and Helfat 2010; Chiang and Hung 2010; Barge-Gil 2010). Such microscopic view on networks is important, as a broader, deeper and more varied search may cause a greater ability among firms to adapt to changing circumstances, namely, in markets and technology fields, and ultimately for firms to innovate and grow (Teece 2007, 2009).

6.2.1. Resource-based view and dynamic capabilities

According to resource-based views, firms are ‘bundles’ of resources that are used to create products or services providing value to customers in a competitive environment. Resources are the set of tangible and intangible assets tied semi-permanently to the firms, like capital, research facilities, and experience gained from the past. Firms compete to possess scarce and hard to imitate resources in order to be capable to stand ahead of other firms (Wernerfelt 1995; Barney and Clark 2007). Networks can be seen as a specific resource in gaining knowledge, especially those types of knowledge outside the technical knowledge that is already owned by spin-off firms derived from university research (Mustar 1997; Pérez-Pérez and Sánchez 2003; Nicolaou and Birley 2003; Johansson et al. 2005; Tether 2002; Walter et al. 2006; Drechsler and Natter 2012). However, spin-off firms only build and maintain open networks if they own the required resources, like financial resources, experience and management time available, and can master the risks that also come with open relationships. The outcome of this ‘balancing’ may be influenced by the pressure of the innovation strategy, namely, the strength of the drive to be in the innovation forefront and competition felt in the market (Urban and von Hippel 1988; von Hippel 1988).

Openness can be seen as part of a firm’s capability to identify opportunities and threats, seize opportunities and avoid risks, and to maintain competitiveness in responding to the rapidly changing business environment (Teece 2007, 2009; Helfat et al. 2007). Openness as a dynamic capability is mainly being developed drawing on learning processes, already available knowledge and networking experience in the founding team and suggested by Zahra et al. (2006), learning processes are central to the development and application of dynamic capabilities, including openness.

Given many trade-offs, spin-off firms may avoid openness in knowledge relationships, like small high-tech firms in general (van der Vrande et al. 2009). An important obstacle is lack of trust in collaborative learning, if the core knowledge is not adequately protected or the protection rules are not transparent (West and Lakhani 2008). Other obstacles happen in the search process, including a lack of knowledge about partners, e.g. large companies which can be trustworthy and the right persons to contact (e.g. Andersson 2008; Lindegaard 2011). A further obstacle is lack of an attractive profile of the spin-off firms themselves as a partner, maybe due to an early stage of the invention causing risks. Table 1 illustrates various modes of open relationships including the potential benefits but also the main potential obstacles preventing (part of) spin-offs to participate in such relationships.

Table 6.1. Potential open relationships by spin-off firms

Modes	**Potential benefits and obstacles**
1. Facility sharing with university	*Benefits*: cost-reduction, learning of new skills. *Obstacles*: -
2. Knowledge exchange (informal) with colleagues at university /incubator, family/ friends	*Benefits*: generation of new creative ideas without costs. *Obstacles*: -
3. Highly exclusive *co-creation* of selected *basic* knowledge with a large firm/institute in which results are shared (high access costs)	*Benefits*: risk-sharing, cost-reduction of generation of key knowledge, shortening of time-to-market. *Obstacles*: often too expensive to participate; spin-offs are seen as less attractive.
4. Exclusive mutual learning with one/few customers, often a launching customer (*co-creation*)	*Benefits*: risk-sharing, cost-reduction, shortening of time-to-market. *Obstacles*: problems of intellectual ownership; spin-offs are seen as less attractive.
5. Creation of knowledge on *application* (problems), e.g. with user groups, university, large firms in *co-creation and co-testing*, like in 'living labs'	*Benefits*: cost-reduction in learning on customer demand including trustworthy solutions; shortening of time-to-market. *Obstacles*: intellectual ownership rules are not transparent; too small managerial power.

Source: Adapted from van Geenhuizen and Soetanto (2013)

Aside from resources and capabilities required for open knowledge networks, the literature also forwards external factors that influence the need for openness among firms, mainly market factors. Firms could balance the trends of rapid technological change and competition in technology and markets by using ideas and knowledge from other organizations in internal product and process development and accessing the market, this provided that there is an adequate IP protection (Lichtenthaler 2005; Chesbrough 2007; Drechsler and Natter 2012).

The size and diversity of the knowledge pool accessed through networks may also depend on the assets available in the local environment of the firms. In views on urban innovation, the stance is taken that centrally located cities offer a larger and more varied set of assets or 'shared resources'. This situation would make it more urgent for firms in remote cities to compensate for missing local resources.

Following Feldman (1994) and de Jong and Freel (2011), it can be argued that more openness among firms is a response to resource deficiencies in the local/regional area.

According to the above lines, a model of openness is designed in this chapter using three sets of factors, namely (1) resources factors, enabling internal learning processes, indicated by firm age and firm size, and pre-start experience and education of the founding team, (2) a set of strategy factors that determine the nature and direction of the learning processes, i.e. the early growth strategy, science-based versus non-science-based activity and innovation strategy, aside from (3) competition in the market and the urban location. Of course, such division into sets of factors is somewhat artificial because the factors influence each other, this will be dealt with in the study by checking for multi-collinearity and by searching for interaction effects. Each individual factor will be discussed in more detail below.

6.2.2. Enabling factors

Enabling factors refer to resources and capabilities that set the potentials of a firm in internal and external learning. The enabling factors discussed below are firm age and firm size, founding team size and founding team's pre-start experience and education.

Firm age and size

Age and size of spin-off firms and the relation with learning, innovation and growth have received strong attention in the literature (Rothaermel and Deeds 2004; Rothaermel et al. 2007). It seems - while learning abilities increase with age and size – that openness tends to increase proportionally. Thus, larger firms are more open than smaller ones, as observed by Drechsler and Natter (2012). Within each growth process, however, at one point in time, increases tend to slow down and are followed by a decreasing trend. This pattern is known in broader economic work as decreasing returns (Arthur 1994; Grabher 1993).

From an evolutionary perspective, the phenomenon can be described as follows: accumulated capabilities of firms may after some time start to limit the scope of search and the capacity to comprehend and apply new knowledge (Cohen and Levinthal 1990; Nelson and Winter 1982). Thus, after some years of fast increase of openness capacity and openness diversity, spin-offs and their managers may face capacity shortages, also named 'attention allocation problem' (Simon 1947; Ocasio 1997). Moreover, locked-in routines grown in past years may cause a larger effort to understand norms, habits and routines in searching and relying on additional external knowledge channels (Laursen and Salter 2006; Dahlander and Gann 2010).

Size of founding team

Founding teams represent different combinations of learning abilities of spin-off firms at start (Colombo and Grilli 2005, 2010). Usually founding teams' size ranges from two to five persons. Research results on the influence of founding team size on performance of young ventures tend to be mixed; some literatures say that with a large size there is a stronger learning in building the initial external networks (Davidsson et al. 2006; Cooper et al. 1994). However, in the broader literature on team management, larger founding teams are assumed to increase the chance of 'social loafing', thereby reducing the learning in building knowledge networks (McShane and Travaglione 2007; Robbins and Judge 2011). In general, 'social loafing' occurs when people exert less effort and perform at lower levels if working in a group compared to working solely.

Education in founding team and participating in training

Knowledge accumulated in the founding team influences the firm's capacity to learn and has a significant role on its learning process (Cohen and Levinthal 1990; Inkpen 1998). While a higher education may have a positive influence on the firm's quality of sensing new knowledge created externally and on acquiring it, it could contribute to a higher level of openness to attract more funding and other resources to the firm (Colombo and Grilli 2010; Shrivastava and Tamvada 2011). However, a higher education may also have a negative impact on firm outcomes, because it causes 'lock-in' based on a relatively strong self-confidence and self-reliance (Beckman et al. 2007; Cohen and Levinthal 1990; Nelson and Winter 1982; Dencker et al. 2009). With regard to education, it can also be expected that founding teams faced with a multidisciplinary education are more open to the external sources partly, due to their larger capability to connect with more diverse partners. Team members might receive market related training and consultancies that help them to be more open to external partners including small and large firms. These types of training might help firms in searching for specific knowledge on market, and provide a better view in competitors and industrial trends specifically (Escribano et al. 2009). The previous argument is the basis for including education level, multi-disciplinary of education and participation in training in the model.

Pre-start experience in founding team (breadth and depth)

Pre-start experience in the founding team has received a lot of attention in research on new ventures performance (van Praag 2003; Lee et al. 2010; Colombo and Grilli 2005, 2010). The focus in this part of the literature is on the type of experience, namely, start-up experience, managerial, organizational and R&D experience, and the similarity of the experience with the sector of the new venture, without empirical research explicitly questioning the influence of these experiences on building networks and on the level of openness.

In the current study, a distinction is made between the breadth of experience referring to diverse areas, like management and R&D, and the depth of the experience, referring to the number of years of experience in the same sector. Beckman et al., (2007) confirm that founding teams with diverse functional backgrounds, breadth of experience in this study, are capable to learn more efficiently and reach entrepreneurial milestones quicker compared to non/less diverse teams, and are also more attractive to specific partners, like investors. These arguments lead to the assumption that with a broad pre-start experience in the founding team, spin-off firms' networks will be more open.

In addition, research shows that new ventures led by experienced managers are better able to identify opportunities and threats because of greater familiarity with their industries and a greater ease in establishing knowledge relations (Cooper at al. 1994; McGee and Dowling 1994; Colombo and Grilli 2005). Conversely, other research demonstrates that prior start-up experience could have a negative impact on firm outcomes, because a deep prior experience may cause 'lock-in' based on a strong self-confidence and self-reliance (Beckman et al. 2007; Cohen and Levinthal 1990; Nelson and Winter 1982; Dencker et al. 2009). Overall, there are different opinions about the impacts of 'depth' in pre-start experience on spin-off firms' learning and openness in networks.

6.2.3. Strategy factors

Strategic choices can be seen as an important set of factors influencing openness in knowledge relations, i.e. the initial growth ambition, nature of innovation activity, and level of 'prospector' strategy, as drawn from a wider literature. First, spin-offs may differ in initial growth strategy based on diverse ambitions, like to remain small, or to become a large company, eventually active around the world. Secondly, spin-off firms can be divided into two broad categories based on the main drivers of innovation, i.e. science or market- and problem-related, and connected learning routines (Tidd et al. 2005; Asheim et al. 2007). Science-based firms create inventions in research drawing on laws of nature and these inventions are often more radical in nature, like in biotechnology, material science and optics, while the other category, non-science-based firms, are involved in engineering or problem-based types of invention with a stronger influence from the market. The two types of innovation practice call for a different learning and use of knowledge networks, the first with a stronger emphasis on using and creating codified scientific and technology knowledge and the last with an emphasis on experience-based and problem-based learning, in other words learning based on doing, using and interacting, also more often in local and regional interaction (Jensen et al. 2007; Martin and Moodyson 2012). For example, science-based spin-off firms are often in rapidly changing environments and, accordingly, need more information and knowledge from financial institutes, public authority, and large firms (Amit and Shoemaker 1993; Mohr et al. 2010). Therefore, science-based spin-offs can be assumed to create a 'more varied and deeper' openness with more diverse partners, which enable them to respond immediately to the developments among competitors, both in technology and market. The other segment of firms can be assumed to have more focused and therefore limited networks, particularly with regard to diversity, as the learning is mostly 'on the job' and in close interaction with users/customers (Jensen et al. 2007).

Thirdly, high-technology ventures may adopt a so-called prospector strategy which reflects involvement in rapid new product development, seeking out new opportunities and taking risks (Miles et al. 1978). A prospector strategy often goes along with being a market pioneer, and the first with innovative new products in different markets. As high uncertainty surrounds the development of new products and new technology applications, prospectors have to maintain flexibility and adaptability, and must be able to scan a wide range of external conditions, trends, and events. They thus need a heavy investment in individuals and groups who scan the environment for potential opportunities, including those in external networks (Miles et al. 1978; Mohr et al. 2010). While the prospector innovators need to be flexible and open towards external sources, it is more likely that the intellectual property is protected among them. Therefore, employing a prospector strategy is assumed to result in higher level of openness, both in breadth and depth of the knowledge pool and socio-economic diversity of knowledge partners, compared to spin-off firms engaged in other innovation strategies.

6.2.4. Competition in the market

Various related studies indicate that the search for external knowledge by innovative firms is strongly influenced by the richness of technological opportunities and by the pressure on search activities of other firms (Nelson and Winter 1982; Teece 1986; Levinthal and March 1993; Chesbrough 2007). The opportunity to integrate external knowledge can help a firm to reduce a product's time-to-market in highly competitive environments. Thus, in industries with strong technological opportunities and strong competition by selected firms, there is often a need to search more widely and deeply in order to get access to critical knowledge sources (Laursen and Salter 2006). This situation underpins the assumption that high levels of competition stimulate openness. However, open knowledge collaboration seems only be stimulated in a situation in which intellectual property (IP) is adequately protected (Drechsler and Natter 2012).

6.2.5. Urban location

The underlying argument is that in cities in remote areas firms tend to compensate for deficiencies in the local environment, such as a relatively poor labor market, lack of specific producer services and lack of launching customers, by connecting more often with partners in other regions and abroad (Audretsch 1998; Feldman 1994, 1999; de Jong and Freel 2010). Among the sampled firms in Trondheim there are various examples of firms connecting with a diverse set of knowledge partners concerning testing, financing, and markets in other Norwegian cities, like

Bergen and Oslo. The danger of ‘lock-in’ is also brought to the fore in the literature concerning the urban environment, indicating a potential ‘over-embedded’ situation, faced with too close and too rigid local networks impeding the exchange of new ideas and providing less diverse knowledge (Grabher 1993; Bathelt et al. 2004). Thus, a strong local network may also cause a reluctance or small desire to build open networks.

A conceptual model of the influencing factors to firm openness is presented in Figure 6.1.

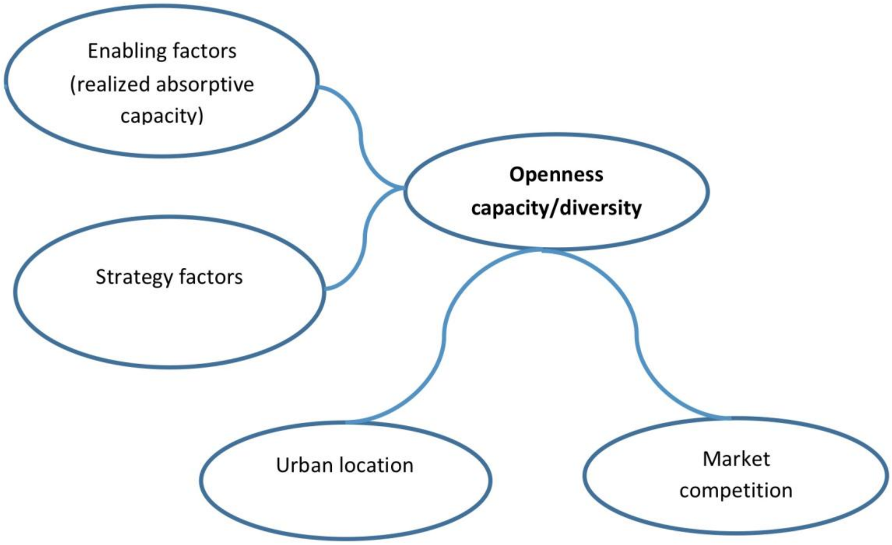

Figure 6.1. A conceptual model of openness in knowledge relationships

The above discussion is summarized in Table 6.2. Note that not all above factors are included in the final models, this as a result of solving multi-collinearity issues.

Table 6.2. Summary of expected influences on openness based on literature

Factor	**Direction of relationship with openness**
Enabling factors (resources, capabilities)	
Firm age and firm size	Positive, eventually inverted U-shape
Size of founding team	Not clear/no consensus
Education level of founding team	Positive, in certain cases negative
Multidisciplinary education of founding team	Positive
Participation in training	Positive
Pre-start experience breadth (founding team)	Positive
Pre-start experience depth (founding team)	Not clear/no consensus
Strategy factors	
Early growth ambition (strategy)	Positive
Nature of innovation activity (science-based)	Positive
Innovation strategy –prospector	Positive
Market competition	Positive (if adequate IP protection)
Urban location (remote)	Positive, but in certain cases negative

6.3. Data, measurement and modelling

6.3.1. Sample

The aim of the study is to picture differences in openness in knowledge networks of university spin-off firms and to explore the determining factors of these differences. Like the study on internationalization in the previous chapter, this study draws on a given sample of 105 spin-off firms, from two technical universities, Delft University of Technology in Delft, the Netherlands and National Technical University of Norway in Trondheim (Note 1). The Netherlands and Norway share a similar, rather risk-avoiding culture in entrepreneurship and are both qualified as innovation followers in 2010, with Norway falling somewhat back in 2012 (ProInno Europe 2010; 2012), while both countries are facing relatively small domestic markets causing similar needs for openness in export among firms. Thus, comparing cities in both countries, the pattern is not distorted by different national influences. Delft is a small town, with 97.000 inhabitants, and it is a part of the southern Randstad metropolitan area that stretches from Leiden in the north via The Hague, Rotterdam to Dordrecht and neighbouring towns in the southeast (Province of South-Holland).

The major industry in South-Holland is commercial and service industry with a notable concentration of port activities, including basic chemical manufacturing, in the Rotterdam-Rijnmond area (Statistics Netherlands 2010). The major industries in Trøndelag area, where Trondheim is, encompass mining, agriculture including farmed fish and processed wood. Note that oil and gas production is the fastest growing sector (Statistics Norway 2010). With regard to size of the economy, the South Holland economy is eight times bigger than the economy of Trøndelag. Trondheim is a single city with 171.000 inhabitants, at a large distance from large cities, for example, the distance from Trondheim to Oslo and Bergen is approximately 400 km and to Stockholm (Sweden) approximately 600 km. Although Trondheim, unlike Delft, is in a remote and rural area, it has an important function as a knowledge city, and it is the third largest city in Norway. Details of the data collection in both cities can be found in the previous chapter.

6.3.2. Measurement

Knowledge networks are measured as ego-networks, meaning that the relationships seen from the firm are analyzed, not the whole network. The measurement is limited to those knowledge relations that really mattered for the firm, with a maximum of five partners. This does not mean that all the firms mentioned five links, it happened quite often that only three or four were given (Soetanto 2009).

The dependent variable openness is measured in two dimensions: knowledge pool capacity and knowledge partners' diversity. The knowledge pool is drawn from the actual networks as shaped after the search process. Knowledge pool capacity, as the 'size' of the external knowledge pool, is conceptualized as a two-dimensional variable composed of breadth and depth (Laursen and Salter 2006). Breadth, number of different types of knowledge domains in the interaction with partners, and depth, tie strength between the firm and its partners, constitute the knowledge pool that the firm actually has shaped and accesses. Therefore, the value of openness capacity is calculated as:

$$Cap = \sum_{i=1}^{n}(B_i \times D_i) \quad (6.1)$$

where n is the number of external knowledge domains (11 potential domains). The breadth B_i is the counted number of partners within a knowledge domain, while the depth D_i requires a further calculation (Appendix 1). It is worth to mention that a large pool of knowledge does not necessarily equal to an efficient and effective use of external knowledge. It is widely acknowledged that weak ties are the source of more exploratory knowledge than strong ties (Granovetter 1983; Levin and Cross 2004). However, the strength of weak ties is highly context dependent, for example, weak ties may be more beneficial for high-status individuals than low-status ones (Lin et al. 1981). Fortunately, the continuous variable formulated in this study allows for a full-spectrum investigation (from weak to strong) of these effects using entropy weight-method (see Appendix 1).

Knowledge partner diversity is seen in the sense of socio-economic diversity, meaning various social and economic circles, including spatial ones. Using the latter assumes that with increasing distance, the newness of social circles connected to ego increases, as the likelihood of established face-to-face contact decreases with distance (Bathelt et al. 2004). Knowledge partner diversity is calculated as the product of socio-economic background diversity and local/regional diversity, as follows:

$$Div = Hs\ (1 + \frac{EI}{2}) \qquad (6.2)$$

where $$Hs = 1 - \sum_{k=1}^{8} (\frac{a_k}{N})^2 \qquad (6.3)$$

where a_k is the number of partners with a different socio-economic background, with $k = 1\ (large\ business), 2\ (government)\ \ 3\ (university), 4\ (small\ business), 5\ (family\ or\ friends), 6\ (venture\ capatialists), 7\ (lead\ customers),\ 8\ (others).\ N$ is the total number of partners a university spin-off interacts with, and a higher value indicates a higher level of socio-economic background difference (min: 0; max: 1). In particular, spatial orientation is calculated as:

$$EI = \frac{E_p - I_p}{E_p + I_p} \qquad (6.4)$$

where E_p is the number of external, non-local, partners, accessible through more than 60 minutes car driving, and I_p is the number of local partners ($E_p + I_p = N$). A high value indicates a relatively strong external orientation and access to new circles (min: -1; max: 1).

The way in which the various sets of independent variables are measured can be found in Table 6.3.

6.3.3. Modeling openness

The dependent variable is openness, explored for two dimensions, namely, capacity and diversity. Although some non-linear relations are expected between independent variables and openness capacity and diversity (like in the case of firm size and age), linear multiple regression analysis is applied because some other variables in the model are measured as categorical or binary variables. The type of regression analysis used is the backward stepwise method and this type matches the exploratory nature of the current study. In this method, first, the full regression model is run including all the independent variables. Next, the variables are removed one by one in such a way that the model power, R^2, and statistical significance of the model decrease to the smallest extent. Furthermore, a high correlation between firm size and firm age urges to include one of them, and firm size is selected to produce stronger models in terms of R^2. The same holds for breadth and depth in prestart working experience; these are not used in one and the same model (see Appendix 2).

With regard to the diagnostic tests, generally all tests are satisfying the assumptions: no severe concerns for outliers, the residuals are normally distributed and homogeneous, and the tests for model specification errors produce satisfactory results (Appendix 3). In addition, endogeneity of the model is addressed and the results indicate no need for endogeneity concerns (Appendix 4).

6.4. Descriptive analysis

With regard to openness capacity, the size of the knowledge pool, the spin-off firms use slightly more than half of the available knowledge domains on average, given a choice of eleven different knowledge types. Openness capacity shows a mean score of 6.3 with a standard deviation of 3.8 and a range of 1.1 to 12.3. Concerning openness diversity, spin-off firms are facing a rather low level as witnessed by an average of 0.35, considering a theoretical maximum score of 1, this is most probably because it requires much effort to make a choice in the dilemma and build a diverse network while increasing particular risks, or there is a small awareness on this strategy. Firms with a relatively high diversity score seem eager to access knowledge from different partners in bringing their invention to market, like partners in large firms, eventually acting as launching customers, government officials on regulation in testing, and partners in financial investment.

The most often used knowledge domain is that of new markets/customers and competitors (together 28 per cent of all domains mentioned), but technology and its development come in second place (23 per cent). This pattern suggests a dual orientation of the networks, both development-oriented and market-oriented, meaning that broadly speaking spin-offs at young ages are faced with both sides of activities, exploration and exploitation. It also illustrates that openness in knowledge networks has a larger coverage than merely open innovation dealing with products and processes.

Table 6.3. Descriptive statistics

Variables	
Number of spin-off firms	105
Openness Capacity: continuous variable indicating size of the external knowledge pool, constructed using 'breadth' and 'depth'	Avg.: 6.3; s.d.: 3.8; Min-max: 1.08-12.3
Openness Diversity: continuous variable indicating diversity of the external knowledge pool, including heterogeneity of partners and spatial orientation	Avg.: 0.35; s.d.: 0.2; Min-max: 0-0.9
Control variables	
Market competition: variable in two levels (many competitors=1)	Many competitors: 56%; Few competitors: 44%
Urban location: variable in two categories of cities, as a dummy (Trondheim=1)	Delft: 58% Trondheim: 42%
Enabling factors	
Firm age: continuous variable as number of years since firm foundation to 2006	Avg.: 4.9; s.d.: 3.1; Min-max: 0-10
Firm size: continuous variable as number of full time equivalent in 2006	Avg.: 7.2; s.d.: 6.9; Min-max: 0.5-51
Size of founding team: continuous variable as team members at foundation	Avg.: 2.3; s.d.: 1.2; Min-max: 1-5
Pre-start experience breadth: continuous variable as sum of years of founders' experience in research/ management, and other areas	Avg.: 1.1; s.d.: 0.9; Min-max: 0-3
Pre-start experience depth: continuous variable as sum of years of founders' pre-start working experience in similar sectors	Avg.: 7.3; s.d.: 13.4; Min-max: 0-73
*Education level of founding team(number of PhD):*continuous variable measuring the members with PhD among founders	Avg.: 0.6; s.d.: 0.9; Min-max: 0-3
Multidisciplinary education of founding team: variable in two categories (Multiple studies=1)	Single discipline (65.7%) Multiple discipline (34.3%)
Participation in training: variable in two categories, yes (1) No (0), as a dummy	Yes (31.4%) No (68.6%)
Strategy factors	
Innovation activity: variable in two categories, science-based (1) versus non-science based (0), as a dummy	Science-based: 27% Non-science based: 73%
Early growth strategy: a compound variable (size and international orientation), in three categories	Large and international (37%); small and international (53%) and small and local (10%)
R&D expenditure: continuous variable as percentage of turnover spent on R&D over the last three years *)	Avg.: 39.8; s.d.: 23.1; Min-max: 0-100
Newness in innovation: variable in three levels based on the type of innovation (breakthrough and/or new to the sector)	High level: 46% Medium level: 29% Low level: 25%
Patenting strategy: variable in two categories, patented (1) versus non patented (0), as a dummy	Patented: 44% Non patented: 56%
Prospector strategy: continuous variable derived from R&D expenditure, newness in innovation and patenting strategy (see factor analysis of the above three indicators, see Appendix 5)	Avg.: 0.1; s.d.: 0.85; Min-max: -1.4 - 1.1.

* Some highly innovative firms do not yet produce turnover because they have no sales; however, they often raise large amounts of national subsidies and/or investment capital through collaboration with a large

firm, like in medical biotechnology. In these cases, the amount of subsidy/capital from large firms was taken into account.

Table 6.4. Knowledge domains

Knowledge domain	**Abs. Frequency**	**Percentage**
New market or customer	180	17
Competitors and industrial trends	115	11
Managerial advice in managing the new firm	130	13
Organization issues and human resources development	61	6
Technological advice	117	11
Product and service development	123	12
Research facilities, equipment and testing	31	3
Cooperation and partnership with other firms	50	5
Legal aspects (e.g. patent, taxes)	78	8
Financial-related information (e.g. loan, venture capital)	83	8
Others	61	6
Total knowledge domains mentioned	1029	100

As for type of partners, most often indicated are senior executives of large firms and professors at university, while high-level policymakers in government and family and friends are least involved as knowledge partners. The picture as illustrated in Table 6.5 points to a dominance of research collaboration with large firms and with the university, the last may include facility sharing (university), co-creation and various outsourcing relationships that are described in Table 6.1 as potential open relationships between spin-offs and partners. Similar with the knowledge domains, the network partners reflect a dual development- and market orientation.

Table 6.5. Knowledge partners

Type of knowledge partner	**Abs. Frequency**	**Percentage**
Large firm (senior executive)	122	33
Government (high level officer)	28	8
University (professor)	109	29
Small business (owner)	63	17
Family or friend	27	7
Others (e.g. financial investor)	24	6
Total knowledge partners mentioned	373	100

In the descriptive analysis in the remaining section, the attention is on the independent variables, to start with enabling factors (Table 6.3). Concerning the enabling factors, indicating resources and learning abilities, on average, the sampled spin-off firms were almost five years old, with a standard deviation of three years. They employed on average seven full time equivalents (fte) at the time of survey, but the standard deviation indicated quite some differences within the sample. The spin-off firms started on average with two team members in the founding team, with a maximum of five members. Regarding pre-start experience in the founding team in terms of breadth, the spin-off firms had on average one type of experience, including research, management or other types of experiences. The share of the sample facing one type of experience was 62 per cent. In addition, spin-off firms' founders with experience had on average seven years of relevant experience in the same sector/industry. Taking education of founders into account, the teams had on average less than one member on the PhD level, with a variation between zero and three, and most of the teams, nearly 66 per cent, had members from the same educational discipline. Moreover, increasing capabilities through a substantial training seems not common, as is witnessed by a low participation rate among the teams interviewed (31 per cent).

With regard to strategy factors, the early growth strategy can be summarized as follows: 37 per cent intended to become large with an international orientation, and the remaining 63 per cent intending to remain small, most of them (53 per cent) with an international orientation and only 10 per cent focusing on the domestic market. In addition, spin-off firms active in sectors with science-based learning were a minority (27 per cent) while most of the firms (73 per cent) were in other sectors, meaning that their learning and innovation were driven by problems or market demand mostly in engineering/design sectors. Most spin-off firms in this category were software firms. The spin-off firms spent on average 40 per cent of their turnover/income on R&D activity, but a relatively large standard deviation indicated quite some differentiation, for example, there were research firms spending almost 100% of their turnover on R&D. Regarding the newness of innovations, 46 per cent of the spin-off firms were dealing with products/processes in the highest category, namely, a breakthrough and new to the sector, while 25 per cent were involved in low level of newness, namely, an already accepted product, process or service with minor improvements. This result connected with the patenting strategy, with 44 per cent of the spin-off firms in the sample employing such a strategy. Given a high correlation between R&D expenditure, newness in innovation strategy and patenting strategy, these three variables are 'bundled' in a new variable, 'prospector strategy' (see Appendix 5). The average score is 0.1 on a scale of -1.4 to 1.1.

Regarding competition in the market, 56 per cent of the firms were active in a highly competitive environment and the rest, 44 per cent, operated in environments with a few competitors. With regard to the urban location, spin-off firms representing large metropolitan areas, Delft, had a share of 58 per cent and those representing cities in remote regions, Trondheim, had a share of 42 per cent in the sample.

6.5. Drivers of openness

Initially, by including only the control variables in the models, it is found that high level of competition is positive and significant in openness capacity model produced a higher level of R^2 of 0.04, compared to openness diversity model. This might imply to the more important role of the control variables of urban location and level of competition of market on openness capacity compared to diversity. Including all the variables in the model, the capacity model found to be relatively weak with two beta-coefficients significant and positive, namely size of the founding team, indicating the enhancing influence of more resources and learning capabilities, and the strength of competition in the market (that remained significant). The partner diversity model is much stronger than the capacity model, with all beta-coefficients of enabling factors significant, except for two variables of level of education and participation in training. Among the strategy factors, only prospector strategy tends to be important. Note that size of the founding team tends to influence partner diversity different compared to size of the firm (different signs), namely negatively; this is also different from the openness capacity model in which the influence is positive. In addition, an urban location in a remote region tends to enhance openness diversity in presence of enabling and strategy factors. The full model outcomes are shown in Table 6.6.

Backward, stepwise, regression analysis is used in the exploration of drivers of openness, presented in the optimal models, Table 6.7. The optimal model on openness capacity and on openness diversity are presented in Model 1 and Model 2 (a and b) (Table 6.7). The optimal models turn out to be only slightly stronger compared to full models, witness ΔR^2 of 0.03 for openness capacity and 0.04 for openness diversity, and the trends remain the same. First, the model on openness diversity is much stronger than the one on openness capacity as is witnessed by R^2 of 0.53 and 0.20 respectively. Thus, the set of variables in the diversity model produces the highest level of explanation of openness in knowledge relationships. The beta-coefficients of spin-off size, size of the founding team, multidisciplinary of education and breadth of experience of founding team, prospector strategy as well as urban location are significant in this model. The finding that diversity can be better understood is probably because it clearly differentiates between network partners, each with their distinct expertise and learning processes. As a second trend, the size variables (founding team and entire firm) tend to work into opposite directions for openness capacity compared to openness diversity, indicating that these two dimensions represent different attributes of knowledge networks and require different firm qualities in solving the dilemma's, namely, smallness within the firm or founding team makes it necessary to extend externally, but also: smallness within the firm or founding team makes it impossible to extend externally and look for diverse partners due to shortage in resources and capabilities.

Table 6.6. Regression analysis of openness in knowledge networks: control variable and full models

	Openness Capacity (Knowledge pool)		**Openness Diversity (Knowledge partners)**	
	β (s.e.)	β (s.e.)	β (s.e.)	β (s.e.)
Control variables				
Urban location (Trondeim=1)	0.24 (0.20)	0.19 (0.21)	0.32 (0.20)	0.33 (0.17)*
Market competition	0.35 (0.20)*	0.40 (0.21)*	-0.02 (0.20)	0.10 (0.17)
Enabling factors				
Firm size	-	-0.20 (0.14)	-	0.72 (0.11)***
Size of founding team	-	0.63 (0.31)**	-	-0.64 (0.24)***
Pre-start experience breadth	-	-	-	0.19 (0.10)**
Pre-start experience depth	-	-0.02 (0.02)	-	-
Education level of founding team	-	-0.10 (0.18)	-	0.01 (0.14)
Multidisciplinary education of founding team	-	-0.16 (0.23)	-	0.43 (0.18)**
Participation in training	-	0.40 (0.45)	-	0.45 (0.36)
Strategy factors				
Innovation activity (science-based =1)	-	0.25 (0.27)	-	0.30 (0.21)
Early growth strategy	-	0.04 (0.11)	-	0.04 (0.09)
Prospector strategy	-	0.03 (0.14)	-	0.21 (0.11)*
N	105	105	105	105
F	2.13	1.70*	1.30	7.99***
R^2	0.04	0.17	0.02	0.49
Root MSE	0.99	0.96	1.00	0.76

* p<0.1; ** p<0.05; *** p<0.01

a) In order to gain normal distributions, various variables are transformed, namely, firm size, pre-start experience depth and openness capacity using logarithm transformation and size of founding team using square root transformation.

Next, the capacity and diversity model are discussed in more detail. Among enabling factors, based on resources and capabilities, the beta-coefficient of size of founding team is significant in models, while the direction of the influence is different, a positive impact on openness capacity and a negative impact on openness diversity. Accordingly, larger founding teams tend to contribute to a higher level of the capacity dimension but to a lower level of the diversity dimension. The beta-coefficient of firm size is significant in openness diversity model, while the direction of the influence is different, with a positive impact on openness diversity. The previously indicated two-directional influence of size may be an explanation for this result; another explanation may be that non-linear relations underlie the pattern, namely, with small size a strong increase and with a larger size a flattening of this increase in openness. For the last one, 'social loafing' may be an important explanation, namely, the situation in which people exert less effort and perform at lower levels if working in a group compared to working solely. Furthermore, as can be expected from evolutionary thinking and path dependency views, a larger depth in pre-start experience (more years in the same sector) tends to hamper openness capacity. However, breadth of pre-start experience appears to work the other way around, a larger breadth (more years in different areas) in experience tends to stimulate larger openness diversity. Multidisciplinary of education of founding team found to have a positive influence on openness diversity. The two last variables might indicate that diversity in education discipline and experience of founders might facilitate their collaboration with diverse partners in later stage of firm development. With regard to innovation strategies, the results found to be partly as expected. A prospector strategy tends to stimulate openness diversity. These results comply with those of Drechsler and Natter (2012) who find a positive influence of internal R&D on the degree of openness, but contradict those by Barge-Gil (2010) who finds that open innovators are less R&D intensive. This contrasting finding can, however, be related to different ways of measurement. The positive influence of being active in science-based activity, found to be significant only in extended diversity model.

In addition, a strong competition in the market environment tends to make firms searching for more types of knowledge more deeply. This result is in line with the findings Klevorick et al. (1996) who find that in existence of high levels of technological opportunities and extensive investments in search by other firms, a firm often need to search more widely and deeply in order to gain access to critical knowledge sources. However, this result on competition is not revealed by the work of Drechsler and Natter (2012). Generally, substantial risks are involved in collaboration in innovation as open innovation potentially weakens the protection of the knowledge base and core competences that constitute the firms 'competitive edge' (Chesbrough 2007; Lichtenthaler 2009). And finally, the urban location variable produced significant results and partly confirms other studies: spin-off firms in Trondheim, as a 'remote city', tend to be more open in knowledge relations with regard to diversity (de Jong and Freel 2010).

In a next step, interaction effects argued on the basis of resource-based views are explored in Model 2b (Table 6.7). The variables assumed to have interactions are *firm size* and *urban location*. The results are consistent with the resource-based view and urban innovation views: more diverse knowledge relationships tend to be accessed in Trondheim because of the shortage of local resources, and this is reinforced by firm size, due to more resources available in larger firms as well needs for more different resources in larger firms. Also, the positive influence of being involved in science-based activity turns out to be just significant. Overall, the model improvement is modest (ΔR^2 of 0.04).

Table 6.7. Stepwise regression analysis of openness: optimal models

	Model 1 Openness Capacity (Knowledge pool)	**Model 2a Openness Diversity (Knowledge partners)**	**Model 2b Openness Diversity (Knowledge partners)**
	β (s.e.)	β (s.e.)	β (s.e.)
Control variables			
Urban location (Trondheim=1)	-	0.37 (0.16)**	0.40 (0.15)**
Market competition	0.42 (0.17)**	-	-
Enabling factors			
Firm size	-0.33 (0.11)***	0.81 (0.11)***	0.85 (0.10)***
Size of founding team	0.78 (0.25)***	-0.45 (0.22)**	-0.53 (0.21) **
Pre-start experience breadth	-	0.20 (0.08)**	0.21 (0.08)**
Pre-start experience depth	-0.04 (0.02)**	-	
Multidisciplinary education of founding team	-	0.30 (0.18)*	0.31 (0.17) *
Strategy factors			
Innovation activity (science-based =1)	-	0.31 (0.19)	0.32 (0.18)*
Prospector strategy	-	0.21 (0.09)**	0.21 (0.09)**
Interaction effects			
Firm size x Urban location			0.52 (0.18)***
N	105	105	105
F	6.17***	15.35***	15.42***
R^2	0.20	0.53	0.57
ΔR^2			0.04
Root MSE	0.87	0.71	0.68

* p<0.1; ** p<0.05; *** p<0.01

As a final step curvilinearity, using quadratic terms and cubic terms, is explored for those influences on openness that are measured on a ratio scale , namely, firm age, firm size, size of the founding team, pre-start experience, early growth strategy and prospector strategy. The quadratic terms of the variables are inserted in an 'empty' model, one by one. The coefficients are, however, not significant in any of the models. Next, the cubic terms are included in an empty model to explore openness based on the equation $y=ax^3$. In the openness capacity model, the coefficients were not significant. Firm size, breadth of prestart experience and prospector strategy are found positive and significant in the openness diversity model, keeping the signs compared to the respective optimal linear model. While this exploration disproves any U-shape type of relationship between the influencing factors and openness dimensions, it proves non-linear relationships in terms of cubic function for some variables. The somewhat contradictory results and the influence of non-linearity reveal a complex mechanisms at work in shaping firm openness as apparent through enabling and strategy factors.

Table 6.8a. Curvilinearity test of openness capacity

	Openness capacity (knowledge pool)					
	β (s.e.)	β (s.e.)	β (s.e.)	β (s.e.)	β (s.e.)	β (s.e.)
Cubic terms						
Firm age	0.01 (0.06)					
Firm size		-0.09 (0.06)				
Size of founding team			0.79 (0.90)			
Pre-start experience depth				-0.001 (0.001)		
Early growth strategy					-0.01 (0.04)	
Prospector strategy						0.02 (0.1)
N	105	105	105	105	105	105
F	0.01	2.49	0.77	1.26	0.02	0.04
R^2	0.00	0.02	0.01	0.01	0.00	0.00
Root MSE	1.00	0.94	1.00	1.00	1.00	1.00

Table 6.8b. Curvilinearity test of openness diversity

	Openness diversity (knowledge partners)					
	β (s.e.)	β (s.e.)	β (s.e.)	β (s.e.)	β (s.e.)	β (s.e.)
Cubic terms						
Firm age	0.07 (0.06)					
Firm size		0.25 (0.05)***				
Size of founding team			-0.54 (0.90)			
Pre-start experience breadth				0.13 (0.05)**		
Early growth strategy					0.03 (0.04)	
Prospector strategy						0.19 (0.10)*
N	105	105	105	105	105	105
F	1.21	23.38***	0.36	6.71**	0.62	3.78*
R^2	0.01	0.19	0.00	0.06	0.01	0.04
Root MSE	1.00	0.91	1.00	0.98	1.00	0.99

* p<0.1; ** p<0.05; *** p<0.01

6.6. Discussion and recommendation

Open innovation is ‘en vogue’. In order to quickly respond to changing environmental circumstances, shorter product life cycles, increasing competition both in technology development and in customer markets, firms are reconsidering their innovation strategy and including higher degrees of openness in their knowledge interaction with various partners. However, much has remained unknown about such strategies, in particular the driving forces among small high-technology firms and the dilemmas they are facing given the need for more resources, namely, market knowledge and marketing skills while facing the lack of specific resources to build and manage the required networks.

This chapter contributes to the empirical literature as follows. First, given the almost neglected area of small firms in open innovation research, except for van de Vrande et al. (2009), Gassman et al. (2010) and Hayter (2010), the chapter presents results on a specific category of small firms, namely university spin-off firms, for which openness seems urgent given the lack of specific resources. The chapter is unique in this respect because the knowledge networks involved were established by relatively young firms, potentially not yet reflecting the intense market competition that mature firms are facing and still strongly influenced by the founding team's (limited) learning capacity. Secondly, given a lack of understanding of what openness in knowledge relationships constitute in terms of main dimensions, the current results are based on two different openness dimensions, capacity and diversity. Thirdly, given a lack of insight derived from quantitative approaches and, in most recent quantitative studies, a still limited coverage in measurement of openness (Barge-Gil 2010; Drechsler and Natter 2012), a rich measurement of openness was used in a quantitative approach, including size of the knowledge pool, constructed using 'breadth' and 'depth' in various knowledge domains (openness capacity), and diversity in this knowledge pool including socio-economic differences between network partners and spatial orientation (openness diversity). The mostly used knowledge domains were market and competition-related and technology-related, whereas the mostly connected knowledge partners were large firms and universities. As a fourth contribution, the chapter identified the following 'drivers' of openness as important *positive* influences on one or two openness dimensions: firm size (openness diversity) and size of founding team (openness capacity), multidisciplinary education and experience (breadth) of the founding team (openness diversity), and being involved in a prospector strategy and science-based activity, last only in an extended model (both openness diversity). In addition, a competitive market environment tended to influence openness capacity in a positive way, and a remote urban location tended to have the same effect but in this case for openness diversity.

The results on enabling and strategy factors show a positive influence of firm size, science-based nature of innovation (only in an extended model), and being located in Trondheim on openness (diversity) that are in line with the results on large distant international knowledge relationships as discussed in Chapter 5. In contrast to large distant international knowledge relationships, education level (number of PhDs) and participation in training do not influence openness in knowledge relations. In general, more similarities are found between the model of establishing large distance knowledge relationships and openness diversity compared to openness capacity, implying that the first two types of networking strategies by firms might be similar and gaining benefits from similar mechanisms.

In addition, the modeling results brought the following trends to light. First, the model on openness diversity is the strongest, R^2 of 0.57 including one interaction effect, most probably because openness diversity clearly differentiates between network partners, each with their distinct expertise and learning processes, and young spin-off firms clearly need to use this diversity while moving from mainly exploration to mainly exploitation. Secondly, in the overall picture of openness, enabling factors (referring to resources and capabilities present in the firm) tend to have a stronger influence compared to strategy factors. A third trend is that firm size, size of the founding team and pre-start experience tend to show *opposing* impacts on the two openness dimensions, indicating a different dealing with the dilemma of open networking for small firms (van de Vrande et al 2009): much external resources can be gained but specific resources and capabilities need to be owned, e.g. to enable searching, building and maintaining relationships while preventing certain risks. In addition, non-linear influences play a role through a cubic function for openness diversity. Overall, the somewhat contradictory results and influence of non-linearity indicated a set of complex mechanisms at work in shaping the external knowledge partner configuration, as apparent through enabling and strategic factors. This situation calls for further research and applying other non-linear and advanced models in exploring openness dimensions. Moreover, a positive influence of a high competition level on openness capacity, is in line with another study by Klevorick et al. (1996) who find that in existence of high levels of technological opportunities and extensive investments in search by other firms, a firm often need to search more widely and deeply in order to gain access to critical knowledge sources, however, this finding is not revealed in a study by Drechsler and Natter (2012).

With respect to policy making and management, the results showed clearly low levels in openness among spin-off firms, which call for recommendation to managers of incubation programs and to managers of spin-off firms. If managers of incubators intend to contribute to increasing openness of spin-off firms, they can only impact upon those types of factors that can be easily influenced. One is size of the founding team: our ‘contradictory’ results suggest a need for a balance between a too small size and a too large size. This also holds for including experienced managers (in-sector experience) in the founding team; there needs to be a balance between too little experience and too much experience, the last situation potentially causing path dependence. Another influencing factor was prospector strategy. Promoting such an innovation strategy might increase openness, while at the same time also larger risks tend to emerge, urging for a selective approach. However, based on indications for optimal degrees of openness, openness in knowledge networks ought not to be considered an aim in itself, but a strategic management tool (Drechsler and Natter 2012). Therefore, in developing an openness strategy, spin-offs' managers need to monitor not only the firms' networks and main drivers, but also the impact of open knowledge networks on performance in innovation and growth.

There were also some limitations in this study. First, due to the relatively small sample size, openness in knowledge networks was explored by a limited number of factors, thereby excluding other features of openness. Increasing the model parameters could particularly improve the model for openness capacity which found to be relatively weak in the current study. Second, due to data limitations no accurate picture could be sketched of the inflow of knowledge to the firm or outflow to other firms and organizations, only some indications could be given. Thus, future research would include the picture of different inflow and outflow modes in a detailed way, as well as collaborative innovation (co-creation) to better describe the openness in knowledge relationships and the drivers involved. Third, the analysis of firm openness was based on cross sectional data; as a result, dynamics of openness was beyond the scope of the study. Future research could make use of longitudinal data on firm openness to give a better insight into the developments in openness over time, and particularly for different ages and years after professionalizing the team as openness might decrease in aligning with different environmental changes (Laursen and Salter 2006; Chesborough et al. 2006).

Note 1

The given database was derived from a meta-analysis of growth of 40 university-related incubators (van Geenhuizen and Soetanto 2009), pointing to the universities in Delft and Trondheim as sufficiently contrasting and viable cases. In a next step, the population of spin-offs from TU Delft and NTNU was delineated on the basis of the following criteria. First, the firms needed to satisfy the condition of commercializing knowledge created at a university and were to be found in Delft/Trondheim or their surrounding regions. Further, the firms had to satisfy the condition of "survived in 2006", and being no older than 10 years. All firms in this population (150) were contacted with an overall response rate of 70% (105 firms). Data were collected using a semi-structured questionnaire in personal face-to-face interviews with entrepreneurs in 2006. Note that excluding non-survivors is a common source of bias in the results of studies like the current one; however, it appeared that mortality rates among university spin-off firms are relatively low in the European Union. Mustar et al. (2008) suggest that 75% of firms survived after six years. Local experts in Delft even suggested 80 to 90% (personal communication).

Appendix 1

Calculation of depth as a dimension of knowledge capacity

There are B_i partners within the knowledge content i, each has a "depth" as d_j ($j = 1 \ldots N$), which is a composite variable derived from frequency of interaction (r), duration of relationship (u), and entrepreneurs' assessment of closeness of the relationship (c, M-rank categorical variable) (Burt, 1992):

$$\begin{cases} r_j = r \times l \\ u_j = \ln(u+1) \\ c_j = \frac{c}{M} \end{cases} \tag{6.5}$$

where r_j, u_j and c_j are the frequency of interaction, duration of relationship and entrepreneurs' assessment of closeness of the relationship for the partner $j. r \times l$ can be seen as "frequency-distance product", which intends to eliminate the distance as a 'comtamination' of freqency of interaction. These variables will be further normalized as follows:

$$\begin{cases} r_j^* = r_j/(\max(r_j)) \\ u_j^* = u_j/(\max(u_j)) \\ c_j^* = c_j \end{cases} \tag{6.6}$$

where r_j^*, u_j^* and c_j^* are the normalized variables of r_j, u_j and c_j (for each variable, min: 0; max: 1). Here the min-max normalization is used to scale the value between 0 and 1, and make the data better interpretable. A weighting method is proposed here derived from the thermodynamic theories. Entropy is a measure of the degree of disorder, uncertainty, or randomness of a probabilistic system, while information entropy can also measure the effective amount of information of the data. The Entropy-weight method is applied in many fields of study, like information science, transportation and etc. (Cheng 1996; Franke and Piller 2004; Song et al. 2007). If there are m criterions and n objects which need to be evaluated, the entropy of the *i*th criterion is defined as *Hi*:

$$H_i = -k \sum_{j=1}^{n} f_{ij} \ln\left(f_{ij}\right) \quad (i = 1,2,\ldots,m) \tag{6.7}$$

where $f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}$, and $k = \frac{1}{\ln(n)}$. And it is assumed that when $f_{ij} = 0$, $f_{ij} \ln\left(f_{ij}\right) = 0$.

In essence, the larger the entropy H_i, the less information it can provide. For instance, if most of the partners are judged as very close to the entrepreneurs, the assessment of closeness (r) would not be an efficient indicator for the tie strength, since it cannot provide enough information or distinction to differentiate various strengths of tie. Therefore, the entropy weight of the *i*th criterion can be calculated by:

$$w_i = (1 - H_i)/(m - \sum_{i=1}^{m} H_i) \tag{6.8}$$

Using formula 4 and 5 and the data, the entropy weights for the three indicators of tie strength can be calculated, as $w_u = 0.30, w_r = 0.38, w_c = 0.32$. And the formula for the "tie strength" is as follows:

$$D_j = w_u u_j^* + w_r r_j^* + w_c c_j^* \tag{6.9}$$

where for D_j, a higher value indicates a relatively tighter relation, thus deeper "depth" (min: 0; max: 1). Apparently, the spin-off has a deeper "depth" with the first partner, or a stronger tie.

Appendix 2

Table 6.9. Correlation matrix (n=105) a)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Urban location	1.00														
2	Market competition	-0.11	1.00													
3	Firm age	-0.21*	0.20*	1.00												
4	Firm size	-0.16	0.03	0.53*	1.00											
5	Size of founding team	0.14	-0.07	-0.35*	0.17	1.00										
6	Pre-start experience breadth	0.33*	-0.05	0.01	-0.07	0.06	1.00									
7	Pre-start experience depth	0.14	0.00	0.13	-0.09	-0.14	0.63*	1.00								
8	Education level of founding team	0.19	-0.12	-0.09	-0.15	0.01	0.37*	0.39*	1.00							
9	Multidisciplinary education of founding team	0.20*	-0.05	-0.01	0.33*	0.32*	0.06	-0.04	-0.00	1.00						
10	Participation in training	-0.04	0.05	-0.28*	-0.08	0.19	-0.13	-0.00	0.07	-0.09	1.00					
11	Innovation activity	0.11	-0.14	-0.21*	-0.28*	-0.06	0.11	0.13	0.29*	0.07	0.25*	1.000				
12	Early growth strategy	-0.00	-0.01	-0.02	0.21*	0.10	-0.09	-0.12	0.03	0.14	-0.08	0.21*	1.00			
13	Prospector strategy	0.12	-0.40*	-0.37*	-0.14	0.07	0.20*	0.15	0.28*	0.03	0.03	0.38*	0.26*	1.00		
14	Openness capacity	0.10	0.16	-0.18	-0.14	0.21*	0.09	-0.14	-0.04	-0.04	0.18	0.17	0.09	0.08	1.00	
15	Openness diversity	0.16	-0.03	0.15	0.52*	-0.00	0.22*	0.11	0.09	0.37*	-0.00	0.09	0.21*	0.17	0.17	1.00

* p<0.05
a) Spearman correlation coefficients.

Appendix 3

Table 6.10. Linear regression diagnostic test outcomes: openness models (n=105)

Diagnostic	***Description***	***Capacity***	***Diversity***
Model		Model 1	Model 2a
Detecting unusual and data causing bias	Residuals, leverage, Cook's D and DFBETA, etc.	Checked	Checked
Test for normality of residuals	(1)Inter-quartile range (iqr) test; (2)Shapiro-Wilk test	(1) iqr test:1outlier (2) Shapiro-Wilk: z: -1.155 p-value: 0.88	(1) iqr test:1 outlier (2) Shapiro-Wilk: z: -1.838 p-value: 0.97
Test for heteroscedasticity of residual	(1) White's test; (2) Breusch-Pagan test	(1) chi^2: 18.52 p-value: 0.86 (2) chi^2: 0.38 p-value: 0.54	(1) chi^2: 32.20 p-value: 0.46 (2) chi^2: 1.61 p-value: 0.20
Test for multicollinearity	Variance inflation factor	Mean VIF: 1.12	Mean VIF: 1.17
Test for model specification error	Ovtest	F: 0.48 p-value: 0.70	F: 2.47 p-value: 0.07

Appendix 4

The prospector strategy variable is a candidate to be endogenous, as this strategy may follow from the strategy of openness. Being more open could lead to a stronger prospector strategy. Moreover, strength of the prospector strategy could be better expressed by other exogenous variables, like nature of innovation activity (science-based or not) (Fu 2012). Therefore, the endogeneity of this variable was checked in each model. Both Durbin and Wu-Hausman statistics are calculated for the endogeneity test. Overall, there are no indications for endogeneity.

Table 6.11. Endogeneity test

	Instrument Variable	Durbin	Wu-Hausman
Openness Diversity	*Nature of innovation activity*	Chi2(1) = 0.03 p = 0.86	F(1,94) = 0.03 p = 0.87

Appendix 5

In order to reach reliable factor analysis results, three methods are used, namely, principle factor, principle-component factor and maximum-likelihood factor. The results are highly consistent and robust.

Table 6.12. Calculation of prospector strategy using factor analysis

Methods	*Principle factor*			*Principle-component factor*			*Maximum-likelihood factor*		
Variables	*Number of items*	*Retained factors*	*Factor loading*	*Number of items*	*Retained factors*	*Factor loading*	*Number of items*	*Retained factors*	*Factor loading*
Newness in innovation strategy	3	1	0.61	3	1	0.78	3	1	0.61
Patenting strategy			0.77			0.87			0.83
R&D expenditure			0.76			0.86			0.80

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Diversity of the Team and Networks and Growth Among University Spin-off Firms*

Abstract

Spin-off firms are considered a major channel through which university knowledge is brought to market. However, in the European Union, these firms display on average a moderate growth, including a substantial variation. This chapter is an attempt to increase understanding of this variation by considering diversity as a main influence both from networks and the firm's team, while adopting a resource-base and diversity perspective. Using data on 105 university spin-off firms, it appears that diversity in external networks has a stronger influence on growth from the start compared to diversity in founding teams. Diversity in social networks (domestic) and international networks tend to positively influence employment and turnover growth, the first reflecting increasing returns. Surprisingly, diversity in founding teams, i.e. education type and prestart experience, tends to exert a negative influence on growth (turnover). Exploration and exploitation activity occurs apparently more successfully through external networks, than through the founding team in the early years. However, interaction of network diversity with the level of competition in the customer market indicates a negative influence, causing a subtle balancing between team and network. With regard to urban location, a location in a large metropolitan area tends to enhance growth and to reinforce benefits from social networks here. The chapter closes with research and policy recommendation.

7.1. Introduction

While the previous two chapters had a focus on the emergence of two major attributes of knowledge networks of spin-off firms, internationalization and openness, the current chapter address the resources, capabilities and learning of these firms, mainly in founding teams, and the influence of the founding team as compared to networks on growth.

The commercialization of university knowledge through spin-off firms has attracted attention in regional and national policies in Western Europe since the early 1980s, increasingly so since the early 2000s (Etzkowitz 2001). As university spin-off firms develop inventions and other potentially commercial knowledge, they are thought to contribute to a wider diffusion of university knowledge into the

* A modified version of this chapter, M. Taheri as the first author, co-authored by Marina van Geenhuizen as a supervisor, was presented at the 53rd European Regional Science Conference, August 2013, in Palermo, Italy. A later version of the chapter was submitted to Long Range Planning. The investigation of Propositions 3.1(a,b), 3.2 and 4.1 posed in Chapter 2 are not directly addressed in this chapter, but the results are discussed in the overall reflection on propositions in Chapter 8.

business community, to the enhancement of high-technology entrepreneurship in a region and to an improvement of relevant infrastructures (e.g. Shane 2004; Huggins and Johnston 2009). However, university spin-off firms in the European Union display low levels of employment growth (Mustar et al. 2006; Wright et al. 2009; van Geenhuizen and Soetanto 2009). This chapter examines why many university spin-offs are facing a small growth while only small segments do grow substantially, taking different types and levels of diversity in networks and teams into account.

There is a long tradition in management studies that takes diversity as a factor that makes a difference in growth, for instance with regard to human capital of the founding team (Thornhill and Amit 2003; Teece 2007; Beckman et al. 2007; Colombo and Grilli 2005, 2010) but also to the networks that may work as a ‘compensation’ to get access to external resources (Shane and Stuart 2002; Rickne 2006). In the literature on diversity in start-up firms’ teams, two different approaches can be identified, namely, the one focusing on similarity attraction and perception of members of other groups as less attractive, trustworthy, etc. (similarity attraction paradigm) leading to a larger chance of conflict and negative impact on growth, and the one in which the emphasis is on cognitive resources and concomitant richness in skills, abilities and knowledge, promoting creativity, innovation and problem-solving (cognitive resource diversity paradigm) (Williams and O’Reilly 1998; Horwitz and Horwitz 2007). According to the first line of argumentation, within team differences, namely education type differences could create group fault lines, taking different types of disciplines into account, through which teams members find difficulty in understanding each other’s language (Colombo and Grilli 2010; Shrivastava and Tamvada 2011). By contrast, according to the cognitive resource perspective, within team diversity, namely in education type could positively influence team skills and abilities and increases knowledge richness (Hambrick et al. 1996; Williams and O’Reilly 1998; Chowdury 2005; Horwitz 2005).

Often used attributes of ‘within team diversity’ are age, gender and cultural background of team members, but also education and prior work experience. Education for example, may differ between science, engineering and humanities, and between lower levels focusing on practical skills and higher levels focusing on conceptual skills (e.g., Foo et al. 2005; Colombo and Grilli 2010). Diversity has also been associated with what is named firm ambidexterity, a specific diversity that is concerned with the capacity of the firm to deal with exploration and exploitation simultaneously (O’Reilly and Tushman 2004). Firm ambidexterity began attracting attention as early as the 1970s (March 1991) and there is a growing interest today due to the fact that research results on the influence of ambidexterity on growth have remained divergent (e.g., Bondwell and Chermack 2010; Datta 2011).

As indicated in the previous chapters, the literature also points to external networks as a source of diversity. Most start-ups in the their early years tend to rely on social networks, including partners with a similar background, like colleagues in incubators, family and friends, but also, and often later on, specialized partners from different backgrounds (Larson and Starr 1992). These networks tend to compensate the shortage in human and financial capital and other resources, a vision already developed in the late 1980s (Aldrich and Zimmer 1986; Bruderl and Preisendorfer 1998) and more recently (Tether 2002; Pérez-Pérez and Sánchez 2003; Nicolaou and Birley 2003; Johansson et al. 2005; Walter et al. 2006), partially in the frame of ‘open innovation’ studies (e.g. Chesbrough 2003; Drechsler and Natter 2012). In open innovation, firms gain knowledge from external partners and/or provide own knowledge to such partners purposively in order to accelerate internal innovation and expand the use of external innovation, respectively (Chesbrough 2003; Enkel et al. 2009). However, the number of studies on small firms has remained limited, with notable exceptions like van der Vrande et al. (2008).

There seems a consensus about a positive influence of network partners with diverse social backgrounds, integrating several spheres in society including places (local and global), and through the involvement of a larger diversity in information and knowledge on firm growth (Rodan and Galunic 2004; Simsek 2009). However, the risk of building too diverse networks has also been forwarded which, given the limited firm resources, cannot be properly managed by small start-up firms, potentially leading to decreasing returns. The idea of non-linearity has been largely overlooked in research, with exceptions like Laursen and Salter (2006) and Clercq et al. (2012).

Given the previous short review, the chapter is a response to the inconsistent results in studies on diversity in founding teams, when it comes to young high-technology firms’ growth (Pelled 1996; Powell et al. 1996; Simsek 2009). It is also a response to a lack of insight into the impact of diversity on growth through external networks among small firms, given the increase in adoption of open innovation (Lichtenthaler 2012). The research question addressed is as follows: To what extent does diversity, through characteristics in the founding team and in external networks, influence growth among spin-off firms?

The chapter is organized as follows. In section two, the theoretical background and model building regarding the growth of spin-offs are discussed. This is followed, in section three, by an explanation of the methodology, model specification and measurement issues. In section four, descriptive statistics are presented, followed by an examination of the results of the model exploration and hypotheses testing in section five. In the final section, conclusions and recommendation are presented.

7.2. Theoretical views and model building

7.2.1. Introduction

According to the upper-echelon perspective, the quality of the founding team and management team has main impacts on the performance of start-up firms (e.g. Agarwal et al. 2004; Fern et al. 2012). In young spin-off firms, given the absence of hierarchical structures, the tasks of coordination and strategic planning are mainly performed by the founding team (Finkelstein and Hambrick 1996; Daily et al. 2002). In this vein, a large number of studies in recent years focused on team diversity (Ensley and Hmieleski 2005; Amason et al. 2006; Schjoedt and Kraus 2009; Fern et al. 2012), in terms of age, gender, cultural background (nationality), education, functional and industry experience, business skills, academic members and etc. (Shrader and Thompson 2006; Beckman et al. 2007).

The resource-based view is a major approach to firm growth in which the emphasis is on getting access to resources, enabling a firm to gain better growth opportunities compared to its competitors, while adjusting to the requirements of a changing environment. Resources are a set of tangible and intangible assets tied to the firms, like capital, research facilities, and experience gained from the past. Firms compete to possess scarce and hard to imitate resources in order to be capable to stand ahead of other firms (Wernerfelt 1995; Barney and Clark 2007). Diversity in founding teams and networks may enable a positive use of resources if the founding team members remain integrated by emphasizing benefits from richness in skills abilities and knowledge.

In the current chapter, attention is focused on diversity of team members in education type (discipline) and type of prestart work experience, because the other diversity dimensions addressed in the literature, like cultural or ethnic diversity, gender, show minor variation in the sample of firms. In addition, age and education level diversity are found to have high correlations with other variables in the model, the reason why they are removed from further analysis and discussion. The challenge of the current chapter is to explore the impact of team diversity, and its direction, because there is no consensus in the results so-far. Also, the focus is on network diversity, by taking different social backgrounds of network partners into account (Powell et al. 1996; Grandi and Grimaldi 2003; Reagans and McEvily 2003). The challenge here is to explore non-linearity and various interaction effects because this has been addressed only in a few studies to date.

7.2.2. Hypotheses: team diversity and network diversity

Diversity in Team Education

According to one line of argumentation, education type differences could create group fault lines (social categorization). Group fault lines could particularly arise with different types of disciplines through which team members have difficulty in understanding each other's language and narratives (Colombo and Grilli 2010; Shrivastava and Tamvada 2011). For example within a team different members with different educational disciplines, namely, technical, with a more focus on knowledge exploration, and managerial, with a more focus on exploitation aspects, could increases a conflict within a team. By contrast, according to the cognitive resource perspective, diversity in education has a positive impact through the increase in skills and abilities (practical and conceptual) and increase in information and knowledge richness (Hambrick et al. 1996; Williams and O'Reilly 1998; Chowdury 2005; Horwitz 2005). Such a positive influence would particularly be true when the diversity deals with the distinct skills and abilities needed in exploration activity (research oriented) and those needed in exploitation activity (market oriented) (March 1991; Gupta et al. 2006; O'Reilly and Tushman 2007). The opposed lines of argumentation and results lead to the following hypotheses:

Hypothesis 1a. Diversity in founding teams' education type has a positive effect on firm growth.
Hypothesis 1b. Diversity in founding teams' education type has a negative effect on firm growth.

Diversity in Prior Work Experience

Differences in professional experience of team members gained before starting the firm may also cause the rise of social categorization and creating fault lines accordingly (Pelled 1996; Horwitz 2005). Similar to educational differences, there are two opposing lines of argumentation. Less effective founding teams will be those that act according to social categorization and differences in business culture and industry types in which the experience has been achieved. By contrast, the argument may also be that effective teams are those that take advantage of different skills and abilities experienced in previous work and integrate them to avoid experience-based constraints (Delmar and Shane 2006; Fern et al. 2012). Similar to the arguments on education type diversity, advantages may be gained if these skills and abilities constitute a mix of academic and business background allowing for being active in exploration and exploitation simultaneously (e.g. Ensley and Hmieleski 2005; Lubatkin et al. 2006). The opposed lines of argumentation and results lead to the following hypotheses:

Hypothesis 2a. Diversity in founding teams' pre-start experience type has a positive effect on firm growth.
Hypothesis 2b. Diversity in founding teams' pre-start experience type has a negative effect on firm growth.

Diversity in External Networks

The establishment of external networks is seen as a vital way for young high-technology firms to access missing resources and to achieve new competences. In the literature, there is a consensus about the positive impact of diversity in networks on firm performance. This would be more true if these resources and competences enable the firm to increase the ability to deal with exploration and exploitation (Powell et al. 1996; Beckman and Haunschild 2002; Grandi and Grimaldi 2003; Reagans and McEvily 2003; Simsek 2009). In the model, two types of networks as the source of diversity are included. First, the social networks that are typical in the early years with diversity in type of social background of mainly local/regional partners (Brüderl and Preisendörfer 1998; Johansson et al. 2005), and second, international networks as more formal relationships. Though the overall trend in the literature is concerned with a positive effect from network diversity, some authors also address non-linear patterns. For example, too much diversity particularly in the social networks may not be manageable by young high-technology firms that are lacking time, budget and management experience, causing diminishing returns (Ahuja and Lampert 2001). As the overall patterns may be positive, the following hypotheses are phrased.

Hypothesis 3. Partner diversity in social networks has a positive effect on firm growth.
Hypothesis 4. Partner diversity in international networks has a positive effect on firm growth.

Two presumed interaction affects are discussed next in the remaining section, namely, between networks and the urban location, and networks and competition in market, while these two environments as single factors are taken as control variables in the model. In many regional economic studies, the type of urban location is an important factor thought to influence innovative activities and growth of young firms, with large cities in metropolitan areas being better endowed with external resources compared to smaller towns and rural areas (Audretsch and Feldman 1996; Capello 2006). By drawing on theory on agglomeration advantages, it can be expected that firms in large metropolitan areas experience higher growth rates due to a stronger knowledge spillovers, more diversity in the labor market of knowledge workers, presence of launching customers, and an easier access to connecting networks (Gordon and McCann 2000), circumstances that may reinforce a positive influence of network diversity.

Hypothesis 5. A location in a core metropolitan area positively moderates the influence of diversity in social networks on firm growth.
Hypothesis 6. A location in a core metropolitan area positively moderates the influence of diversity in international networks on firm growth.

With regard to competition in the market, a different strength in competition may affect growth patterns (Laursen and Salter 2006), but more importantly, it may call firms to search for diversity in information/knowledge in different ways. Various studies indicate that the search for external knowledge by innovative firms is strongly influenced by the availability of technological opportunities and by the pressure from other firms (Teece 1986; Levinthal and March 1993; Chesbrough 2007). In industries with strong technological opportunities and competitive search by firms, there is a need to achieve a higher diversity in knowledge (Laursen and Salter 2006). In other words, in response to rapid changes in demand and quick technology changes, firms are relatively flexible and agile in activities such as acquiring, scanning, selecting and assimilating of external knowledge and information. Young high-technology firms, however, due to limited resources, cannot easily manage multiple networking activities and taking benefits from them necessary by quick and adaptive responses under fierce competition (Simsek 2009; Mohr et al. 2010). Accordingly, it can be assumed that, although diverse ties have beneficial influences in general, these beneficial influences are 'dampened' in a highly competitive environment. This argument leads to the formulation of the following hypotheses:

Hypothesis 7. Being active in a highly competitive market negatively moderates the influence of diversity in social networks on firm growth.
Hypothesis 8. Being active in a highly competitive market negatively moderates the influence of diversity in international networks on firm growth.

Additional influences

The model controls for some additional factors from various backgrounds. First, the early growth strategy is added as a control variable to the model (Wiklund and Shepherd 2003; Wiklund et al. 2009). For example, the willingness to become a big and internationally operating firm seems to be an important and straightforward influence on the actual growth. Next, year of establishment of the firm, indicating age and cohort effects, and size and education level of the founding team are added as control variables to the model, as these are often mentioned in the literature as influencing growth. While age and experience of founders are found to have contradictory influence on firm performance in the literature (Colombo and Grilli 2005; Feeser and Willard 2006), education level seems a more straightforward positive influence, because team members with a higher education level and higher credibility tend to attract more funding and other resources to the firm (Colombo and Grilli 2010; Shrivastava and Tamvada 2011).

Year of establishment, as included in the model, captures a firm's age, with younger firms facing relatively strong growth problems due to the liability of newness (Stinchcombe 1965; Freeman et al. 1983; Carroll and Hannan 2000) and mature firms being better equipped to face market challenges and overcome threats from the business environment. The year a firm was founded also comprises cohort effects, referring to impacts of events and developments that are clearly fixed in time, such as economic crises. For example, the economic crisis starting in 2000/1 (the end of the Internet bubble, see Kindleberger 2005) and the financial crisis since 2007/2008 may have influenced the growth of firms that were established or were planning to grow in those years, because particular resources, namely investment capital, became more difficult to obtain, and some markets started to shrink. Finally, the size of the founding team is found to have a contrasting influence on firm growth in the literature, namely, a positive influence based on the argument that larger teams are likely to have more resources at their disposal (Feeser and Willard 2006), but negative trends derived from the argument of an optimal team size (Shrivastava and Tamvada 2011) potentially connected with processes like 'social loafing' in larger teams (Robbins and Judge 2011).

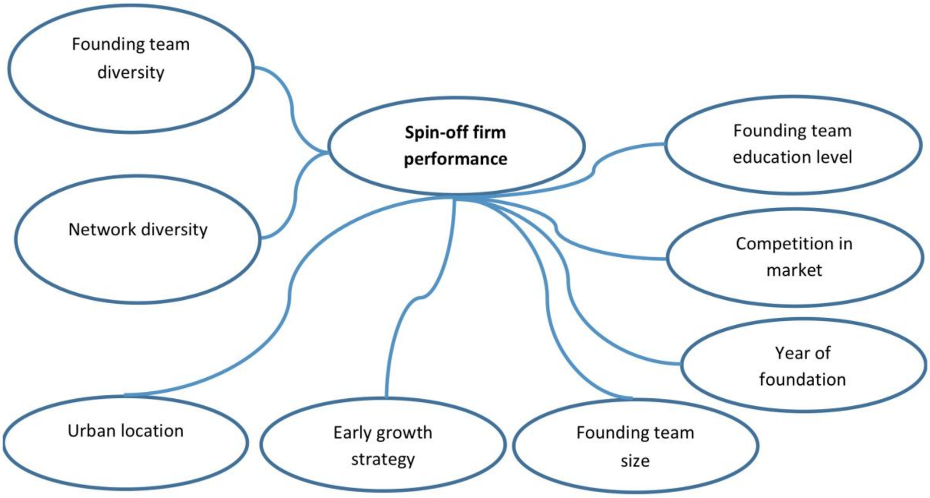

Figure 7.1. A conceptual model of spin-off firms performance (employment growth and turnover growth)

7.3. Methodology

7.3.1. Measuring firm diversity and growth

The above discussed factors are measured at a detailed level, shown in Table 7.1. With regard to the diversity indicators, mainly the Blau index is applied (Note 1). Further, the partner diversity in social networks, as typical networks for young firms, is measured in detail, concerning partners' social background and partners' physical distance (local and regional/national) in Note 2.

In measuring firm growth, different outcomes can be achieved; one is no growth and another even failure. Failure (exit) can be defined and measured in many ways, depending on the perspective and purpose of a given study (see Eurostat-OECD Manual 2007; Oskarsson et al. 2008; Lawton Smith and Romeo 2010 for different definitions of firm survival/failure). From a resource-based perspective, firms as bundles of resources and capabilities can be qualified as failure if their resources/production factors, often employees, are reduced to virtually nothing (Note 3). In this study, firms that reportedly ceased (dissolved) activity (Chamber of Commerce files) and empty firms without turnover are considered as failures. In addition, there are a small number of firms that was taken over recently and subsequently integrated in the acquiring firm. Growth of firms is measured as employment growth and turnover growth (Note 4). Employment growth is the average annual growth between the year the firm was founded and 2010, in full time equivalents (fte). Turnover, as given in the database, is an ordinal variable divided into five classes: no growth (including failure and negative growth), low, medium, high and very high growth. Though failure is not frequently happening among university spin-off firms, in a previous study bias from failure was checked and this indicated no need for concern (Soetanto 2009).

7.3.2. Characteristics of the sample

The sample used is a given sample drawn from two universities in Europe, Delft University of Technology (Delft, the Netherlands) and the Norwegian University of Science and Technology (NTNU) (Trondheim, Norway). In a previous study (Soetanto and van Geenhuizen 2007) the incubator organizations of these universities were identified as two contrasting cases: mainly due to the differences in urban location, core metropolitan (Delft) versus non-metropolitan peripheral (Trondheim). However, no significant differences between the national innovation systems of the two countries were assumed, in light of the fact that the Netherlands and Norway share a similar, somewhat risk-avoiding entrepreneurship culture (GEM 2010), show similar scores on the main European Innovation Scoreboard indicators (ProInno Europe 2011) and both have relatively small domestic markets.

The population of spin-off firms from the two universities satisfies various important conditions: involved in the commercialization of knowledge created at the university, survived to 2006 with an age not older than 10 years, and enjoying at least one type of support from the incubation organization/university. All the firms in the population (150) were contacted and the overall response rate was 70%. In 2006, data were collected using a semi-structured questionnaire in face-to-face interviews with the firms' principal manager(s) (founding team), with a focus on firm characteristics, namely, product/service, sector, firm size, R&D, profile of the founding team members and profiles of the networks, particularly the social network. In 2010, data were collected on firm size (employment and turnover) and on changes in main products/services and status of the firms, using e-mail, telephone, and wherever necessary, websites.

7.3.3. Regression analysis and diagnostics

Multiple regression analysis is applied to explore the influence of a firm's founding team and network diversity on growth. Given a continuous dependent variable (employment growth), ordinary least square regression is a reasonable choice if mostly linear relationships are expected. However, some non-linear relationships are also explored. Further, ordered logistic regression is applied to estimate the influence of the same variables (employment) on turnover growth, this variable is measured as an ordinal variable in five classes. In Tables 7.1 and 7.2, the model results are presented in a stepwise approach, differentiating between the models with controls, the model including team diversity only, the model with network diversity only, the full model including both team and network diversity, and the full model including various interaction effects.

The correlation matrix is in Appendix 1. With regard to the employment growth model, the diagnostic tests meet the assumptions on multi-collinearity (see Appendix 2); there is no indication of multi-collinearity in either model after having excluded various variables (Note 5). In addition, to avoid the empty cell problem in the turnover growth model, failed firms and negative growth firms are merged.

Also, checking for reverse causality and simultaneity bias - since all the explanatory variables, except for network diversity, are measured at firm foundation reveals that there is no cause for concern (Note 6). Regarding network diversity variables, as both diversity through social networks and through international networks are measured after firm foundation, endogeneity of employment growth and turnover growth is tested. In both tests, endogeneity of the dependent variable is rejected, and the results of regression are found to be consistent.

7.4. Descriptive analysis

7.4.1. Survival

A majority of the firms in the sample (77 per cent) experienced no change of status between 2006 and 2010, while a small number failed (eight) or was acquired by and integrated into another firm (five) (in total 13 per cent). There were no major shifts in product, but there was a slight move from research to consultancy. Three of the eight failures involved software and Internet firms, while three others were science-based firms, active in energy, enzyme technology and mechatronics, illustrating low entry and exit barriers, and high levels of technological and market-related uncertainty, respectively (Mohr et al. 2010).

With regard to broad classes of activity, science-based industry, industry in which the innovation is pushed by science, was a minority (27 per cent), while most spin-offs engaged in market-based industries pulled by market demand (73 per cent), either in manufacturing or in services. In services, a somewhat larger share of the firms in Trondheim, compared to Delft, was involved in information technology and engineering, testing, optimization and simulation. It would seem this has to do with their being located in a well-developed energy cluster in the region, which included oil and gas, and wind as a sustainable energy source.

7.4.2. Dependent variables: growth

In 2010, the sampled firms had an average age of 9 years in a range between four and 14 years. Their average annual employment growth between foundation and 2010 was 1.2 fte, with a relatively high standard deviation of 2.6 (Table 7.1). In fact, the majority shows a rather slow growth, as evidenced by a skew-ness of 3.2 and kurtosis of 15.3. A similar pattern is observed in a European study (including incubators in five different cities) for spin-offs in the same age range: an average growth of 1.6 fte per year with a standard deviation of 2.5 (van Geenhuizen and Ye 2012).

Turnover is measured in the current study using broad classes, this in order to prevent non-response. With regard to growth in turnover, 46 per cent of the firms made a shift to the highest turnover category in 2010 (> € 500,000), while 15.5 per cent had no turnover and a few had failed by 2010. Details on other studies that provide numbers on size and growth of spin-off firms are in Note 7. The conclusion is that size and growth are measured over somewhat different years and in slightly different ways making a comparison rather difficult.

In studying the sample, employment and turnover growth are found to go hand in hand in many cases (a correlation of 0.71). Opposing results occur when a strong performance in employment growth is coupled with a weak turnover growth. This refers to firms in science-based industry, developing their product for a long time and recruiting a large number of employees on the basis of external funds and subsidies without substantial turnover. The reverse pattern, strong turnover growth together with a weak employment growth, occurs when firms outsource certain activities to other firms or the university.

7.4.3. Explanatory variables: team and network diversity

Regarding team diversity, education had an average score based on three types of education of 0.51 in a range of 0 to 0.89 (Table 7.1). Most teams only had a technical education background in one area (66 per cent), while a minority (34 per cent) had education backgrounds in more than one technology or a combination of technology and other areas, for instance management. Pre-start work experience shows the following pattern: an average score of 0.48 in a range of 0 to 0.89 taking three types of experience into account: technical/research, managerial and other experience. Sixty two percent of the sample had one type of pre-start work experience.

With regard to network diversity, 62 per cent of the firms in the sample obtained input from diverse international knowledge networks (customers, suppliers, universities); whereas all firms received input from social networks (Table 7.1). However, there were different degrees of diversity in the social networks. On average, diversity in these networks scored at 0.35 in a range of 0 to 0.9, with a standard deviation of 0.2.

Table 7.1. Measurement and descriptive statistics (model variables only)

Variables	**Measurement**	**Descriptive statistics**
Number of spin-off firms		105
Turnover growth since foundatio	A variable in five classes	Failed without turnover: 15.5% X <100,000 Euro: 13.5% 100,000 <=X< 300,000: 13.5% 300,000 <=X< 500,000: 11.5% X > 500,000 : 46%
Employment growth since foundation	Continuous variable as growth between start and 2010 through: (Size2010-Size at start)* 1/firm age 2010) in fte (transformed to a normal distribution)	Average:1.20, Median: 0.55 Standard deviation: 2.57 Min-Max:-1-16.3
Control variables		
Early growth strategy	Variable in three categories, but taken as a dummy variable (large and international=1)	Large firm with an international orientation (37%) Small firm with an international orientation (53%) Small firm with a local orientation (10%)
Competition in market	Variable in two categories as a dummy	Many competitors (56%) Few competitors (44%)
Year of foundation	Continuous variable as the year in which foundation took place	Average:2001.1 Standard deviation: 3.1 Min-max:1996-2006
Urban location	Variable in two categories (cities) as a dummy	Core, metropolitan (58%) versus a remote area (42%)
Founding team education level	Continuous variable as number of doctorate degrees in founding team	Average: 0.61 Standard deviation: 0.88 Min-max: 0-3
Founding team size	Continuous variable as number of team members	Average: 2.29 Standard deviation: 1.19 Min-max: 1-5
Founding team diversity		
Experience type diversity	Continuous variable derived from experience of founders, i.e. technical, managerial and others; calculated using $(1-\sum p_i^2)$, where *p* is the proportion (per cent) of team members in a category and *i* is the number of different categories in a team	Average: 0.48 Standard deviation: 0.39 Min-max: 0 – 0.89
Education type diversity	Continuous variable derived from different education disciplines; calculated using $(1-\sum p_i^2)$, where *p* is the proportion (per cent) of team members in a category and *i* is the number of different categories in a team	Average: 0.51 Standard deviation : 0.32 Min-max: 0 - 0.89
Network diversity		
International networks	Variable in two categories indicating established knowledge relationships abroad (with customers, suppliers, knowledge institutes) or not	Yes (62%), No (38%)
Social networks	Continuous variable as described in Note 2.	Average: 0.35 Standard deviation: 0.2 Min-max: 0-0.9

The remaining section will be devoted to the control variables. The early growth strategy can be summarized as follows in terms of preferred growth: ‘large with an international orientation’ had a share of 37 per cent, ‘small with an international orientation’ had the largest share, namely at 53 per cent of all firms, and ‘small and a local orientation’ had a small minority (10 per cent). The year of foundation averaged at 2001 within a range of 1996-2006, meaning that firms were established before and after the early 2000s crisis. With regard to urban location there were two classes: core metropolitan at 58 per cent versus remote, rather peripheral, at 42 per cent. Competition in the business environment shows, that in 56 percent, many competitors exist and 44 percent of firms see only a few competitors. In addition, founding team education level (measured as number of PhD degrees in the founding team) shows an average of 0.6 in a range of 0 to 3. The type of start indicates that a minority of the spin-offs (32 per cent) was founded by one entrepreneur, while most spin-offs (68 per cent) were founded by two or more entrepreneurs. There is an average size of founding teams of 2.3 in a range of 1 to 5.

7.5. Modeling results

In this section, attention is focused on the influence of diversity in a firm's founding team and in a firm’s network on employment growth and turnover growth, including some non-linear relationships and interaction effects. The model results as presented in Table 7.2 and Table 7.3 include the various steps taken, i.e. entering the set of control variables, founding team diversity variables, network diversity variables and finally interaction effects, all including the model power, R^2, at each step.

In Model 1, concerning employment growth, only control variables are included, while an R^2 of 0.15 is reached. Next, the variables of founding team diversity are added to Model 1. The model power shows a slight increase of 0.01 while no more variables become significant in Model 2. Model 3 improves substantially by adding the two network diversity factors to Model 1, as witnessed by R^2 increasing from 0.16 to 0.34. In this model (Model 3), five variables’ coefficients are significant. Including all the variables in Model 4, an R^2 of 0.34 is reached. Next, in Model 5 to Model 8, various interaction effects are added, with interaction between social network diversity and urban location, producing another substantial increase of R^2, i.e. from 0.34 to 0.44 (Model 6). Model 6, accordingly, found to be the best model. In addition, Model 9 only explores a quadratic function of diversity in social networks, and the results indicate increasing returns.

In the remaining section some results will be discussed in more detail. With regard to the control variables, the coefficient of the number of PhDs in the founding team appeared negative and significant, thus pointing to a smaller growth where founding team members has PhD level skills and experience. This situation can be understood as follows. As 72 per cent of the firms with founding members owning a PhD are involved in highly innovative activities and 40 per cent of them in science-based industries, they are more likely to be involved in longer periods of product development and a lagging employment growth compared to the other spin-offs. With regard to other control variables, the sign of all other significant coefficients in Model 4 are as expected.

Remarkably, inserting diversity through founding team members in the model does not yield significant results. This pattern is in line with part of previous studies, for example, Chowdhury (2005). However, including firm diversity through networks, a substantial model improvement is apparent while the two network coefficients are positive and significant. Apparently, diversity through social networks and through business networks abroad supports a better performance in employment growth. The beta-coefficients in Model 4 learn that the probability of employment growth increases by a factor of 1.18 if the firm has international networks and by a factor of 4.56 if social networks are more diverse. A positive impact of knowledge networking with a variety of partners (customers, suppliers, competitors) and organizations on a global level has also been observed in other studies (Knight and Cavusgil 2004; Clercq et al. 2012). Young high-technology firms might be better in balancing exploration and exploitation through their diverse networks, which is in line with what has been argued in earlier studies (Reagans and McEvily 2003; Simsek et al. 2009). In addition, a location in a core metropolitan area positively moderates the influence of network diversity on firm growth. Models 5 and 6 indicate that firms in core metropolitan areas benefit more strongly from their diverse social networks and international networks in growth compared to firms in more remote cities. As earlier suggested, this might be related to different qualities of the network, namely, a higher frequency of interaction between partners or stronger connectivity with other networks, but also a stronger presence of supportive networks, like with launching customers, in metropolitan areas compared to remote cities.

Moreover, the interaction effect of social networks and competition level is found negative and significant, indicating that being involved in a diverse social network in an environment with many competitors, hinders spin-off firm growth. Apparently, it is hard for spin-off firms to manage and benefit from their external network relationships when they are facing a highly turbulent environment, resulting in lower levels of employment growth.

Table 7.2. Employment growth using OLS

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model6	Model 7	Model 8	Model 9
	β-coeficient (S.E)	β-coeficient (S.E)	β-coeficient (S.E)	β-coeficient (S.E)	β-coeficient (S.E)	β-coeficient (S.E)	β-coeficient (S.E)	β-coeficient (S.E)	β-coeficient (S.E)
Control variables									
Early growth strategy	1.28 (0.50) **	1.24 (0.50) **	0.94 (0.48) *	0.92 (0.49) *	0.88 (0.49) *	0.95 (0.45) **	0.91 (0.50) *	1.02 (0.49) **	-
Competition in market (high level = 1)	-0.64 (0.51)	-0.66 (0.51)	-0.75 (0.45)	-0.75 (0.46)	-0.68 (0.46)	-0.48 (0.43)	-0.36 (0.75)	-0.87 (0.46) *	-
Year of foundation	-0.06 (0.08)	-0.06 (0.08)	-0.00 (0.07)	-0.00 (0.07)	-0.02 (0.07)	0.03 (0.07)	0.00 (0.07)	-0.00 (0.07)	-
Urban location (metropolitan core area = 1)	1.23 (0.50) **	1.21 (0.51) **	1.55 (0.46) †	1.53 (0.47) †	0.46 (0.76)	1.58 (0.43) †	1.49 (0.47) †	1.39 (0.46) †	-
Founding team education level	-0.28 (0.40)	-0.26 (0.40)	-0.64 (0.37) *	-0.62 (0.38) *	-0.52 (0.38)	-0.49 (0.35)	-0.61 (0.38)	-0.50 (0.37)	-
Founding team size	0.26 (0.20)	0.41 (0.26)	0.25 (0.18)	0.23 (0.24)	0.21 (0.24)	0.28 (0.22)	0.22 (0.24)	0.24 (0.24)	-
Founding team diversity									
Experience type	-	-0.30 (0.68)	-	-0.23 (0.62)	-0.54 (0.64)	-0.37 (0.57)	-0.28 (0.63)	-0.32 (0.61)	-
Education type	-	1.07 (0.96)	-	0.03 (0.89)	-0.03 (0.88)	-0.04 (0.82)	0.06 (0.90)	0.12 (0.87)	-
Network diversity									
International networks	-	-	1.20 (0.49) **	1.18 (0.50) **	0.13 (0.77)	1.17 (0.47) **	1.58 (0.78) *	1.05 (0.50) **	-
Social networks	-	-	4.50 (1.32) †	4.56 (1.36) †	4.71 (1.34) †	-0.00 (1.68)	4.52 (1.36) †	8.44 (2.23) †	-
Social networks^2	-	-	-	-	-	-	-	-	6.78 (1.45)***
Interaction effects									
International networks*Urban location	-	-	-	-	1.68 (0.94) *	-	-	-	-
Social networks (mean centered) a)*Urban location	-	-	-	-	-	9.15 (2.23) †	-	-	-
International networks* Competition in market	-	-	-	-	-	-	-0.63(0.95)	-	-
Social networks (mean centered) * Competition in market	-	-	-	-	-	-	-	-5.59(2.59)**	-
N	105	105	105	105	105	105	105	105	105
F	2.94 **	2.35 **	6.06 †	4.77 †	4.72 †	6.58 †	4.35 †	4.93 †	21.69 †
R^2	0.15	0.16	0.34	0.34	0.36	0.44	0.34	0.37	0.17
Adjusted R^2	0.10	0.09	0.28	0.27	0.28	0.37	0.26	0.29	0.17
Root MSE	2.44	2.45	2.18	2.20	2.18	2.04	2.21	2.16	2.35

* P<0.1, ** P<0.05, *** P<0.01, †P<0.005; a) This variable is centered around its mean to manage high level of correlations in interaction effects.

With regard to growth in turnover, a different modeling is necessary, namely ordered logistic regression, with the following results (Table 7.3). In Model 1, only the set of control variables is included. In Model 2, the variables covering founding team diversity are added, with pseudo-R^2 slightly increasing, from 0.06 to 0.09. An improvement of the model strength also occurs after inserting diversity of networks (Model 3), from 0.06 to 0.11. In the full model (Model 4), a pseudo-R^2 of 0.14 is reached while six variables are found to be significant. After adding various interaction effects, the best model gives a pseudo R^2 of 0.16 (Model 5).

In more detail, the results on the control variables indicate the following trends. The early growth strategy has consistently a positive effect on turnover growth. With regard to the founding year, firms that started earlier tend to experience a higher turnover growth, which may be because of easy access to financial and technical resources compared to younger firms (Freeman et al. 1983; Carroll and Hannan 2000). Taking birth cohort and period effect into account, firms founded before 2000 have faced better chances of realizing turnover growth, possibly because, before the crisis, opportunities and access to resources were more favorable.

When considering diversity in the founding team, education level and pre-start working experience are found to cause a smaller turnover growth. As seen in the previous modeling of employment growth, the signs are mostly negative, but the coefficients not significant. The trend of founding team diversity hampering growth can be ascribed to a higher level of conflict in teams with large diversity, in the context of strategic decisions (Hambrick and Mason 1984; Pelled 1996; Simsek 2009) to be made at a relatively young firm age while facing a lack of management abilities and behavioral capacities. In contrast to founding team diversity but similar to employment growth, diversity through international networks and social networks found to have a positive influence on growth.

In addition, as already suggested by the employment growth model, a location in a core metropolitan area positively moderates the influence of network diversity on turnover growth (Model 5), indicating that firms in core metropolitan areas benefit more strongly from their international networks in promoting growth compared to firms in more remote cities. As also suggested by employment growth, this be related to different connectivity qualities of the network in core metropolitan areas compared to remote areas which are not captured by this study. Moreover, also suggested by the employment growth model, the interaction effect of network diversity and business competition level is found negative, but only significant for international networks, indicating that being involved in networks abroad in an environment with many competitors, tends to hinder spin-off firm growth. This situation could also indicate that spin-off firms are not able to manage their external network relationships in highly turbulent environments in the early years of their existence.

Table 7.3. Turnover growth, using ordered logistic regression analysis a)

Variables	Model 1	Model 2	Model 3	Model 4	Model5	Model 6	Model 7	Model 8
	Logit coefficient (S.E)	Logit coefficient (S.E)	Logit coefficient (S.E)	Logit coefficient (S.E)	Logit coefficient (S.E)	Logit coefficient (S.E)	Logit coefficient (S.E)	Logit coefficient (S.E)
Control variables								
Early growth strategy	0.91 (0.40) **	0.84 (0.41) **	0.96 (0.44) **	0.87 (0.45) *	0.89 (0.46) *	0.91 (0.45) **	0.85 (0.45) *	0.91 (0.46) *
Competition in market (high level=1)	-0.23 (0.41)	-0.13 (0.41)	-0.27 (0.43)	-0.13 (0.43)	-0.06 (0.43)	-0.02 (0.44)	0.75 (0.68)	-0.23 (0.45)
Year of foundation	-0.23 (0.06) †	-0.25 (0.07) †	-0.23 (0.07) †	-0.27 (0.07) †	-0.29 (0.07) †	-0.26 (0.07) †	-0.27 (0.07) †	-0.27 (0.07) †
Urban location (core metropolitan area = 1)	0.56 (0.39)	0.47 (0.40)	0.70 (0.41) *	0.59 (0.42)	-0.37 (0.65)	0.69 (0.43)	0.51 (0.42)	0.52 (0.42)
Founding team education level	0.14 (0.31)	0.23 (0.32)	-0.21 (0.34)	-0.13 (0.35)	-0.04 (0.35)	-0.10 (0.35)	-0.06 (0.35)	-0.10 (0.35)
Founding team size	0.21 (0.16)	-0.01 (0.20)	0.29 (0.17) *	-0.08 (0.21)	-0.10 (0.21)	-0.08 (0.21)	-0.12 (0.21)	-0.09 (0.21)
Founding team diversity								
Experience type	-	-1.04 (0.54) *	-	-1.03 (0.57) *	-1.40 (0.60) **	-1.18 (0.58) **	1.24 (0.59) **	-1.10 (0.57) *
Education type	-	-0.93 (0.77)	-	-1.81 (0.84) **	-1.95 (0.85) **	-1.88 (0.84) **	-1.80 (0.84) **	-1.77 (0.84) **
Network diversity								
International networks	-	-	1.12 (0.45) **	1.21 (0.47) **	0.28 (0.67)	1.23 (0.47) ***	2.20 (0.77) †	1.18 (0.47) **
Social networks	-	-	2.36 (1.31) *	3.03 (1.34) **	3.30 (1.36) **	1.61 (1.65)	2.95 (1.36) **	4.65 (2.60) *
Interaction effects								
International networks* Urban location	-	-	-	-	1.63 (0.86)**	-	-	-
Social networks (mean centered)*Urban location	-	-	-	-	-	3.79 (2.80)	-	-
International networks* Competition in market							-1.47 (0.88) *	-
Social networks (mean centered) b) * Competition in market								-2.20 (2.97)
N	104	104	104	104	104	104	104	104
LR Chi square	19.81 †	25.83 ***	33.42 †	42.82 †	46.43 †	44.79 †	45.65 †	43.39 †
Pseudo R^2	0.06	0.09	0.11	0.14	0.16	0.15	0.15	0.15
Log likelihood	-139.21	-136.21	-132.41	-127.71	-125.91	-126.73	-126.30	-127.42

* P<0.1, ** P<0.05, *** P<0.01, †P<0.005; a) turnover measured in five classes
b) Social networks (mean centered): This variable is centered around its mean to manage high level of correlations in interaction effects.

Next, the model outcomes are summarized while comparing them with the hypotheses (Table 7.4). With regard to diversity in the founding team, diversity in education type and experience type of founders had a negative impact on turnover growth, a trend also visible for experience type and employment growth but without statistical significance (Hypotheses 1 and 2). This result is an indication that a high level of diversity reduces team cohesion and create dissonance and conflicts among team members, which in turn leads to a lower growth (Shrivastava and Rao 2010; Shrivastava and Tamvada 2011). With regard to networks, both diversity through social networks and through international networks had, as assumed, a positive impact on growth (Hypotheses 3 and 4). Also, a trend of non-linearity was found in the influence of social networks on growth.

Moreover, a location in a metropolitan area tended to positively moderate the impact of network diversity on firm growth, however, this influence is not significant in the turnover growth model for social network diversity (Hypotheses 5 and 6). Another trend was also found: the level of competition in the market negatively moderates the impact of network diversity on firm growth; however, this impact was not significant for two models (Hypotheses 7 and 8). Overall, the pattern of the entire analysis indicates the importance of dealing with dual objectives of exploration and exploitation *outside* a spin-off firm's boundaries at young ages and supported by a metropolitan location, but also of certain disturbing circumstances like a high level of competition.

Table 7.4. Summary of hypotheses testing

Dependent variables a)	***Employment a)***	***Turnover a)***
Founding team diversity		
H1(a-b)-Education type (+/-)	Rejected (not significant)	Supported (-)
H2 (a-b)-Experience type (+/-)	Rejected (not significant)	Supported (-)
Network diversity		
H3-Social networks (+)	Supported (+)	Supported (+)
H4-International networks (+)	Supported (+)	Supported (+)
Interaction effects		
H5-Social networks *Urban location (+)	Supported (+)	Rejected (not significant)
H6-International networks*Urban location (+)	Supported (+)	Supported (+)
H7-Social networks * Competition in market (-)	Supported (-)	Rejected (not significant)
H8-International networks* Competition in market (-)	Rejected (not significant)	Supported (-)

a) within brackets the assumed sign(s) and the observed signs (employment and turnover).

7.6. Conclusion

While the previous two chapters were concerned with the emergence of particular network characteristics of spin-off firms, this chapter aimed to improve understanding of what networks as opposed to founding teams contribute to growth of these firms, with the emphasis on diversity and with growth measured as employment growth and turnover growth. Average annual employment growth found to be 1.20 fte, in a negatively skewed pattern, indicating a weak growth for many firms since their start. However, turnover growth showed that almost 50% of all firms reached 500.000 Euro or more in 2010. In an analysis of the literature, it appeared that most early research on diversity and firm growth, drawing on the 'similarity attraction paradigm' and the 'cognitive resource diversity paradigm', has yielded contrasting results. Using data on 105 university spin-off firms in the current study, a clear trend was found that diversity in social networks (domestic) and international networks has a positive influence on employment and turnover growth, the first somewhat reflecting increasing returns on employment growth, broadly confirming the ideas on richness of information in the 'cognitive resource diversity paradigm'. In contrast, with regard to founding team diversity concerning education type and prestart working experience, a negative influence was found mainly on turnover growth, broadly confirming the ideas on the rise of 'fault lines' between group members based on similarity and preventing to act as an integrated unit according to the 'similarity attraction paradigm'. The results would mean that being involved in exploration and exploitation occurs more successfully through networks than through the founding team in the early years of spin-off firms. However, networks tend to negatively influence growth in highly competitive environments, thus requiring a subtle balancing of spin-off firms in (re)building their team and in shaping their networks.

With regard to control variables in the models, the early growth strategy in terms of high ambitions has an important impact on growth, as has the year a firm was started, however the latter in a negative sense and as far as turnover growth was concerned, referring to better opportunities for firms established before 2000. Although education level was found to be significant, the sign was different from assumed: a PhD level resulted in smaller employment growth, this was mainly due to the firms in question being active in more innovative activities and facing longer development times of new products/services. Further, as expected, growth taking place in a core, metropolitan, area was enhanced through networks, except for one turnover growth model.

Overall, it can be concluded that, while the founding team of a young firm's age lacks the ability to benefit from diversity within the team, through establishing a collaborative environment, it is able to benefit from diversity in external networks. The study addresses some important gaps in the existing literature with regard to the impact of diversity on young technology-based firms and their networks, partly in the context of open innovation and the need for exploration and exploitation activity, namely inconsistent results on diversity in founding teams and its impact on growth of small technology-based firms, as indicated by Pelled (1996) and Simsek (2009), and lack of insight into the impact of diversity in external networks on firm performance, as indicated by Lichtenthaler (2012).

The outcomes of this study can be generalized for technical universities in countries in the European Union that share some of the characteristics of the Netherlands and Norway, namely, a somewhat risk-avoiding entrepreneurial culture, a national innovation system causing performance as an ‘innovation follower’ and a small but open national economy, while the universities in question specialize in new technology in seashore activities, mainly energy and transport, for example Denmark, Sweden and part of the UK (the North). In addition, the results involving founding teams and external networks of university spin-off firms tend to allow a generalization for all categories of young high-technology firms (Simsek et al. 2009), however, university spin-offs benefit from being connected to universities, which increases diversity through social networks among these firms, and this is not necessarily true for other young high-technology firms. The same but in a negative sense, may hold for a shortage in market relationships, also typical for university spin-off firms.

This study has also various limitations. The relatively small sample and the database used urged the decision to exclude some factors related to the firm growth, such as the stage in the industry life cycle (Stinchcombe 1965; Eisenhardt and Schoonhoven 1990) as well as network characteristics like centrality (Simsek et al. 2009). Also, the behavioral capacity of team members to collaborate across diverse social units potentially increasing alignment and adaptability has remained beyond the scope of this chapter (Gibson and Birkinshaw 2004). Moreover, the management team characteristics in terms of experience and education, in other words, the level of professionalism, may change over time, after being adapted to emerging management needs, and a firm's network characteristics may also evolve over time as the need to access external resource changes. Accordingly, a longitudinal study would yield a better understanding of the role of diversity and its ‘counterpart’ integration (Vanaelst et al. 2006), with several studies indicating that diversity within the firm gives way to higher level integration in later stages of development (e.g. Jansen et al. 2009). In addition, it needs to be noted that urban location was involved in the study only through two cities, calling for including a larger number of cities in future research.

This study has some practical implications. To increase the growth of young spin-offs (Mustar et al. 2006; Wright et al. 2009; Colombo and Grilli 2010), staffing decisions preferably enhance a low diversity in education type and pre-start experience in the founding team, while decisions to build external networks preferably increase diversity, regarding types of partners and regions, particularly transcending the region and country where the firm is located. At the same time it needs to be kept in mind that these recommendations may have the opposite effect in later stages of firm development and/or when competition in the market is increasing. In shaping diverse external networks, attention should be given to competition as a strong competition may make the management of diverse networks difficult in early stages of growth of spin-off firms.

Note 1

Harrison and Klein (2007) suggest two distinctive types of within-unit diversity which we adopted in our calculations: (1) separation, in which within unit members differ from one another in their position along a single continuous attribute; for example, in calculating separation in the founders' age, the standard deviation index can be used, and (2) variety, in which within unit members vary from each other qualitatively, for example, in education level, the Blau index can be used, calculated as $(1 - \sum p_i^2)$ Where p is the proportion (per cent) of team members in a category and i is the number of different categories represented in a team. If a team consists of three members and each member has a different educational background, the team score is [1- (1/9+1/9+1/9)] = 0.67.

Note 2

Diversity through social networks is measured taking partners by different social backgrounds, and their physical distance, into account. Hs indicates social background diversity and EI indicates distance to partners and Der represents diversity through social networks:

$Der = Hs \times (1 + \frac{EI}{2})$
where $Hs = 1 - \sum_{k=1}^{8} (\frac{a_k}{N})^2$
where a_k is the number of partners of a different social background, with $k = 1\ (big\ or\ normal\ business), 2\ (government), 3\ (university), 4\ (small\ business),$ $5\ (family\ or\ friends), 6\ (venture\ capatialists), 7\ (lead\ customers), 8\ (others)$. N is the total number of partners a USO interacts with, and a higher value indicates a higher level of social background difference (min: 0; max.: 1),

and $EI = \frac{E_p - I_p}{E_p + I_p}$

where E_p is the number of external, non-local, partners, accessible through more than 60 minutes car driving, and I_p is the number of local partners ($E_p + I_p = N$). A high value indicates a relatively strong external orientation (min: -1; max: 1).

Note 3

In practice-oriented literature, failure is defined as meeting one of the following criterions: (1) disappeared from the Chamber of Commerce list of registered firms, unless as a result of a name change; (2) reported ceased activity/no activity by the firm owner and/or by the incubator manager for at least two years, for different reasons, such as bankruptcy (Eurostat-OECD Manual, 2007); (3) identified by researchers as empty/sleeping firms with no employees and with no income (Oskarsson et al. 2008).

Note 4

Employment growth of failed firms was set as (-1) and employment growth of recently acquired and integrated firms was calculated based on their actual growth. Various robustness checks were performed, by assigning failed firms different growth values, e.g. -10. The results proved to be robust.

Note 5

Various variables show a high level of correlation of above 0.70 (Appendix 1). To avoid problems of multi-collinearity we have excluded various variables, like age diversity in the founding team and education level diversity. Excluding them does not produce omitted variable bias.

Note 6

As suggested by Davidson and MacKinnon (1993), augmented regression test (DWH test) was used to test for endogeneity in the *employment growth* model, using diversity through international networks as instrument variable. Accordingly, we first performed the original regression model and then included the residuals in an augmented regression. If the coefficient of the residual was not significantly different from zero, OLS is not consistent. In this case, $F(1,86)=0.00$ and $Prob > F=0.95$, we concluded that the OLS results were consistent and there was no problem of endogeneity. Because we also assumed that employment growth may influence diversity from social networks, we checked for the existence of such endogeneity. Using Durbin-Wu-Hausman test, the result $F(1,86)=1.90$, $Prob > F=0.171$, indicated that OLS results were consistent and there was no problem of endogeneity. We also checked for endogeneity in the *turnover growth* model, taking diversity through international networks into account. While diversity through international networks measured year(s) after firm foundation, and since it was possible that firm growth facilitated diverse knowledge relationships internationally. In this case, $F(1,85)=3.40$, $Prob>F=0.068$, we concluded that the estimates were consistent at 5% test level.

Note 7

The number of jobs created on average per spin-off is 4.85 fte in 1996-2006. This number increases to 12.8 for 97 survived firms taking the period 1996-2010 into account. Oskarsson et al. (2008), on growth of 130 spin-offs from ETH Zurich between 1998-2007, found that each spin-off creates on average 8.0 jobs (including 115 survived firms in 2007), jobs measured as number of persons employed rather than full time equivalents (fte) which may cause a slight bias. Lawton Smith and Romeo (2012) found average firm size (persons employed) of 40 firms founded before 1994 to rise from 140 (1994) to 354 (2001), and this is equal to 5.35 jobs created per spin-off in this period. These results broadly illustrate a slow growth, but the outcomes are somewhat difficult to compare due to different time-spans and different definitions of employment.

Appendix 1

Table 7.5. Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 Employment growth	1																
2 Turnover growth	0.71**	1															
3 Urban Location (core, metropolitan =1)	0.25*	0.19	1														
4 Competition in market	-0.13	-0.00	-0.09	1													
5 Year of foundation	-0.16	-0.31**	-0.24*	-0.19	1												
6 Period/cohort effect (founded after 2000= 1)	-0.17	-0.24*	-0.24*	-0.26*	0.76**	1											
7 International network diversity	0.17	0.23	-0.02	-0.02	-0.05	-0.00	1										
8 Social network diversity	0.32**	0.25*	-0.22*	0.07	-0.10	0.07	0.27**	1									
9 Size of founding team	0.06	0.05	-0.08	-0.00	0.14	0.08	-0.17	0.03	1								
10 Founding team age	0.04	0.12	-0.11	0.00	-0.23*	0.13	0.29**	0.20*	-0.46**	1							
11 Years of experience of founding team	-0.04	0.03	-0.29**	0.06	-0.04	0.07	0.20*	0.07	-0.29**	0.74**	1						
12 Education level of founders	-0.18	-0.03	-0.14	0.06	0.09	0.21	0.27**	0.12	-0.16	0.45**	0.43**	1					
13 High level of growth ambition	0.34**	0.15	-0.04	0.00	0.10	0.17	-0.15	0.20*	-0.05	0.05	0.00	0.02	1				
14 Age diversity of founders	-0.05	-0.04	0.06	0.05	-0.19	-0.09	0.25*	0.09	-0.74**	0.71**	0.45**	0.23*	0.03	1			
15 Founding team experience type diversity	-0.18	-0.19	-0.09	0.04	-0.11	-0.02	0.02	0.15	-0.32**	0.34**	0.38**	0.16	-0.00	0.38**	1		
16 Founding team education type diversity	-0.00	0.12	0.10	0.04	-0.18*	-0.13	0.25*	0.11	-0.67**	0.47**	0.26**	0.06	0.01	0.81**	0.35**	1	
17 Founding team education level diversity	-0.17	-0.15	0.10	-0.01	-0.15	-0.10	0.19	-0.04	-0.71**	0.47**	0.24*	0.17	-0.06	0.88**	0.33**	0.82**	1

*P<0.05, **P<0.01, a) Spearman correlation coefficient

Appendix 2

Table 7.6. Linear regression diagnostic test outcomes: Employment growth model

Diagnostic	Remarks	Employment growth
Detecting unusual and influential cases	Applying different methods we assess outliers: Residuals; scatter plots; Leverage; Cooks' D ; DFITS, DFBETA.	One outlier found, but excluding it would not change the results substantially.
Test for normality of residuals	Shapiro-Wilk test	Shapiro-Wilk test: Z=2.37 P-value: 0.45
Test for homoscedasticity of residuals	Rvfplot, graphical method with residuals plotted versus fitted/predicted values. White's test; Breusch-Pegan test	rvfplot, no patterns of heteroscedasticity found. White's- test: Chi^2: 36.19 p-value: 0.02 Breusch-Pegan test: Chi^2: 28 p-value: 0.00 No indication of heteroscedasticity.
Test for multicollinearity	Variance inflation factor (VIF)	Mean VIF: 1.54
Test for model specification error	Linktest; ovtest	Linktest: the testing result of -hatsq was not significant at 0.05 level. ovtest: F(3,82)=1.67, p-value: 0.18

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Reflection on Research Questions and Propositions

8.1. Introduction

Bringing university knowledge to the market has become increasingly important and different channels to commercialize university knowledge, including technology projects in collaboration with industries and university spin-offs, have received more and more attention in recent years (D' Este and Patel 2007; Huggins and Johnston 2009; Van Looy 2011; Bozeman et al. 2013). University knowledge, in the form of inventions, is often not ready for the market and needs to be 'polished' and made available through various rounds of modifications and adding value, before it can be marketed as a new or improved product, process or method, which means that various amounts and types of resources are needed. University research teams and spin-off teams use internal resources and capabilities as well as external resources, through their networks, to access valuable and rare resources, leverage their learning capacities and compete in their target markets (Gulati et al. 2000; McEvily and Marcus 2005), which are usually uncertain and involve different levels of competition (Mohr et al 2010).

The pressure to move toward a knowledge economy is quickly becoming stronger in European countries, including the countries examined in this study, Norway and the Netherlands (OECD Review of Higher Education in Regional Development 2010 and OECD Reviews of Tertiary Education 2009). However, the existing knowledge transfer channels between university and industry do not seem sufficiently effective, as witnessed by barriers in university-industry links that make collaborative projects less productive (Bruneel et al. 2010; Van Looy 2011), and limit the ability on the part spin-off firms to create jobs (Mustar et al. 2008; Gilsing et al. 2010), and as witnessed by the modest capacities of technology transfer offices (Geuna and Muscio 2009; van Looy et al. 2011; van Geenhuizen 2013).

With the aim of improving the performance of knowledge commercialization mechanisms, this study looks at two major channels (technology projects at universities and university spin-off firms) and explores the underlying factors to their performance. A summary of the results and the main conclusions is presented in this chapter. This chapter begins with a discussion of the research design in section 8.2. The answers found to the research questions are discussed in section 8.3, followed by the findings with regard to the propositions forwarded in Chapter 2, in section 8.4. The contribution of the study and a conclusion regarding the propositions and modeling results are discussed in section 8.5.

8.2. Research approach, methods of analysis and database

Chapter 2 and Chapters 4 to 7 started with a review of relevant literature and theory on which the constructs were based and connected in a conceptual model. The resource-based view of firms and organizational learning theory, in combination with the related concepts of absorptive capacity and dynamic capabilities, open innovation, internationalization of knowledge relationships, and diversity in founding teams and networks, were used to analyze the commercialization of technology projects and the growth of the spin-off firms. Accordingly, several propositions on the performance of technology projects and of university spin-off firms were formulated in Chapter 2.

After translating the theoretical constructs into measurable units (Chapter 3), the models were specified and explored using empirical data through econometric models, both linear and non-linear regression models, in the various chapters. The focus of analysis was on the level of internationalization in the knowledge networks of spin-off firms (Chapter 5), the level of openness of these networks (Chapter 6) and spin-off firm growth in terms of employment and turnover (Chapter 7). The focus of analysis was also on technology projects, and rough-set analysis was used to study the outcomes of commercialization of these projects, due to the small sample size and in part fuzzy nature of the data (Chapter 4). Special attention was paid to the efficiency of the technology projects, using data envelop analysis, a non-parametric approach to measure the efficiency of decision-making units, on the basis of multiple inputs and outputs.

Technology projects database

In the analysis of the performance of university-driven technology projects in terms of commercialization, two data sets were used that were built in the Netherlands. Firstly, a database was used of almost 370 projects, derived from Technology Foundation STW, presenting different commercialization outcomes, including market introduction, continuation and failure, and secondly, a database derived from an in-depth study of 42 projects, representing the outcomes mentioned above, with a focus on the underlying factors. The projects under examination started between 1995 and 1997, or between 2000 and 2002, to account for the change in economic climate in the early 2000s and the change in attention among universities to the commercialization of knowledge. The in-depth, database was derived from semi-structured interviews that were conducted in 2010 with 33 university research managers. This sample covered a limited number of technology segments, namely, medical life sciences and medical technology, new materials and systems for sustainable technologies, including automotive, and reflected the two periods and also two different regions in the Netherlands, namely, the core metropolitan area and a non-core region.

Spin-off firm database

Data were used on 105 university spin-off firms from two incubators in the Netherlands and in Norway. The selection of these two incubators goes back to a study of growth of university-related incubators in Europe, North America and some Asian countries (van Geenhuizen and Soetanto 2009), in which it was found that stakeholder involvement in establishing and managing the incubator, and the urbanization level of the location tend to determine the growth of incubators (Soetanto 2009). Two incubators, one at the Norwegian University of Science and Technology and one at Delft University of Technology in the Netherlands, were selected because they displayed opposite scores on these two factors (for more details, see Soetanto 2009). It should be noted that, since 2005, there have been many developments in Delft and the single stakeholder involvement quickly evolved into multiple stakeholder involvement, including the municipality, venture capitalists and large consultancy firms. The population of spin-offs from these incubators was selected based on a number of conditions: they all dealt with the commercialization of knowledge created at university, survived until 2006 with an age not older than 10 years, and received at least one type of support from their incubation organization/university. The data were collected using a semi-structured questionnaire in face-to-face interviews with the principal managers, in almost all cases a member of the founding team. To analyze the degree of internationalization in knowledge relationships and the level of openness in these relationships, cross-section data of 2006 were used. Firm growth, in terms of employment and turnover, was measured in 2006 and in 2010, the latter through a short mail questionnaire, supplemented by website analysis.

The sample of spin-offs represented manufacturing and service sectors in both countries. The manufacturing sector included machinery, chemicals, computer and electronic products, while the service sector mainly covers information and communication and professional and technical activities (NACE). The new technologies included new materials and nanotechnology, sensor technology, control systems, biotechnology and mechatronics. A large minority, 42 percent of the firms, were involved in very new, breakthrough and/or new to the sector product development, protected by patents. A smaller part dealt with innovations that were new at a medium level and without patent protection (35 percent), in most cases involving software/hardware applications, and the remaining firms (23 percent) were active in less advanced software or engineering projects, with an established position in customer markets. Most spin-offs (63 percent) had introduced their product/process into the market or were active in related consultancy services. A minority (37 percent) was still in the early development stage or pilot production and subsequent testing. Around 40 percent of the sampled firms were located in Trondheim and 6o percent in Delft.

8.3. Discussion of results and reflection on research questions

In this section, the major research questions of this study regarding the technology projects and university spin-off firms discussed.

8.3.1. Performance and growth

What is the performance of technology projects at university?

Of a large sample of university-driven technology projects in the Netherlands, 26 per cent of older and younger projects failed, while market introduction/use in society turned out to be in 22 percent of the older projects and 15 percent of the younger projects. Thus, both failure and 'success' held true for relatively small minorities of the projects involved. The smaller share of market introduction for younger projects may be caused by a reluctance on the part of industry after the economic crisis of the early 2000s, as well as by the shorter period available for commercialization. Of the older projects, 32 percent still continued after ten years, while 59 percent of the young projects still continued after five years. These large shares indicated long commercialization time lines.

The sample of the in-depth study of underlying causes was selected such that it reflected the outcomes indicated above. Market introduction occurred in 26 percent of the sampled cases (11 cases). The average time that elapsed between the first thoughts about commercialization and market introduction in these cases was 7.2 years, while it took at least one year and 15 years at the most. Half of the projects started since the mid-1990s, and the rest in the 2000s. However, in most cases, the commercialization process started later, namely, when the research manager began making a seriously effort to bring the invention to market. This often happened after three or four years of a PhD research, but it could also happen earlier, when a company started to question the university about a problem and a project was started to solve this problem. Slightly more than half of the projects in the small sample (23) resulted in a spin-off firm.

What are the growth patterns of university spin-off firms over time?

This question was answered by measuring growth in terms of employment and turnover. Employment growth was the average annual growth between the year the firm was founded and 2010, in full time equivalents (fte). Turnover growth was divided into five classes of no growth (including failures and negative growth), low, medium, high and very high growth. The average annual employment growth between the start of the firm and 2010 was 1.2 fte, with a relatively high standard deviation of 2.57, and a relatively high skewness (3.2) and kurtosis (15.3), indicating that many of the firms grew slowly. The average number of jobs created by spin-offs between 1996-2006 was 4.85 fte, which increased to 12.8 fte for 97 firms that survived (not including acquired firms) between 1996-2010. It has to be noted that the age of the firms was different, but not older than 10 years, at the time of the interview in 2006.

Although, compared to other European studies (Oskarsson et al. 2008; Lawton Smith and Romeo 2012), the results of this study indicate a slow employment growth, the outcomes are difficult to compare, due to different time-spans and different definitions of employment. The other growth indicator was turnover. Forty six percent of the firms realized a shift to the highest category in 2010 (larger than 500,000€), while 15.5 percent had no turnover and a few had failed by 2010. Comparing the turnover growth measured in this study with other studies is difficult, because turnover is often measured using size classes instead of absolute figures, while using different border lines between classes.

In 2010, the sampled firms had an average employment size of 15 fte, with a few outliers, including a firm with 110 fte and one with 166 fte. Altogether, the spin-off firms showed a modest performance in terms of job growth, but a fairly good performance in terms of turnover growth.

8.3.2. Patterns of network and ‘drivers’ of underlying network characteristics

> *What is the geographic pattern of knowledge relationships and degree of openness among spin-off firms? What drives spin-off firms to make their knowledge networks international and open?*

A majority of the spin-off firms in the database (62 percent) engaged in international knowledge relationships, often over large distances, and the spin-offs operating outside of Europe outnumbered those who were only active within Europe (33.5 versus 28.5 percent). These results showed a different pattern compared to the findings reported by de Jong and Freel (2010), where 78 percent of the network partners were located in the Netherlands and the rest abroad, both inside and outside of Europe. This difference was potentially caused by our focus on university spin-off firms, which tended to have a stronger international orientation, while de Jong and Freel looked at a broader category of high-technology SMEs, and, secondly, by the type of knowledge relationship, where the relatively limited sourcing activity in our study contrasted with the more comprehensive approach adopted by de Jong and Freel (2010). Due to the relatively large segment of spin-offs already present in the market, market-related sources, mainly customers and suppliers, were the most important source of international knowledge relationships (41 percent), with annual exhibitions/fairs coming in second place (23 percent).

To describe the level of international knowledge relationships two sets of factors were used: a set of absorptive capacity indicators, including potential absorptive capacity and realized absorptive capacity, and a set of firm-related factors, including location. On the basis of ordered logistic regression, seven important factors were identified, which, in terms of absorptive capacity indicators, included

PhD education, participation in training, and a low level of newness (all positive influences on internationalization), and which, in terms of firm-related factors, included being located in remote regions, firm size, science-based activity and international market orientation as strategic choices (also all positive influences). Interaction between a location in a remote city and participation in training also exerted a positive influence. The modeling results were the first of their kind in covering a relatively broad range of absorptive capacity indicators, including potential and realized absorptive capacity (Zahra and George 2002). Good results were realized on three of the eight indicators, while the overall model power remained relatively weak, albeit comparable to similar studies, which supports the finding that absorptive capacity works differently under different circumstances, while it is also difficult to measure absorptive capacity in a direct way (Zahra and George 2002; Murovec and Prodan 2009; Schmidt 2010).

Openness capacity, as the size of the external knowledge pool, had an average score of six in a range of 1 to 12, with a standard deviation of 4. Openness diversity, referring mainly to the social diversity of partners in the knowledge pool, showed somewhat low scores (an average score 0.35 in a range of zero to 1, with a standard deviation of 0.2). Using backward, stepwise regression analysis, the influence of a set of enabling factors (comparable to some of the absorptive capacity factors) and strategy factors on the two openness dimensions was explored. The following ‘drivers’ of openness (positive influences) could be identified: firm size (openness diversity) and the size of the founding team (openness capacity), educational multidisciplinary of the founding team (openness diversity), pre-start experience (breadth) of the founding team (openness diversity), and the strategy factors, prospector strategy (openness diversity) and being involved in science-based innovation (in extended model of openness diversity). In addition, as environmental factors, a competitive business environment (openness capacity) and a remote urban environment (openness diversity) have a positive influence. Openness capacity and openness diversity were found to be clearly different in ‘driving’ factors, with a better model strength for openness diversity, as witnessed by an R^2 of 0.53 versus 0.20. As the linear modeling in this study pointed to some non-linear relationships, various non-linear relationships were explored and some were found. In particular, by taking the cubic terms into account, firm size, breadth of pre-start experience and prospector strategy were found positive and significant in openness diversity model. The results of linear models and the influence of non-linearity revealed a complex mechanism at work in shaping openness of firms’ relationships, expressed in enabling factors and strategy factors.

8.3.3. ‘Drivers’ and barriers in performance and growth: team versus networks

Next, the outcomes concerning the influence of the team (internal) resources and the networks described above on the performance of technology projects and on the growth of the spin-offs are summarized.

How do research team's internal resources and networks influence the technology project performance at university?

By applying rough-set analysis and drawing on the strongest models, it was found that the duration of the collaboration with a large firm and the efficiency of the project tend to be important factors in reaching the commercialization goals of technology projects. A longer collaboration with large firms, in combination with medium-level efficiency, tends to produce the *strongest* performance in commercialization. In next best models, affinity on the part of managers with commercialization, and their ability to combine a scientific curiosity with a more commercial attitude were also found to be important. If the manager has a limited affinity with commercialization and the market is expected to be small, commercialization faces strong barriers resulting in the *weakest* performance.

And how do the spin-off team's resources, and openness and international reach of knowledge networks influence spin-off firm growth?

The influences on the growth of spin-off firms were explored using ordinary least square regression models (employment growth) and ordered logistic regression models (turnover growth), while the analysis emphasized diversity in the spin-off teams and in the knowledge networks. The impact of diversity in the founding team was examined by looking at the education type and pre-start experience type of the founders. Although diversity among founders turned out not to be important with regard to employment growth, but diversity in pre-start experience and education type was found to have a negative impact on turnover growth, which is in line with the ideas on 'fault lines' between group members that prevent them from acting as an integrated unit, according to the 'similarity attraction paradigm'. By contrast, an early decision on the part of the founders to create a big and international firm worked like a 'driving attitude', positively influencing growth in all models.

With regard to networks, the results confirmed the existence of a positive influence of knowledge relationships with a variety of firms (customers, suppliers, competitors) and organizations at a global level, on turnover as well as employment growth. This has also been observed in other studies (Knight and Cavusgil 2004; Clercq et al. 2012). Moreover, the non-linear impact of diversity in local partners is found to influence employment growth from the start, indicating an increasing return on employment growth, which is in line with other studies that indicate that heterogeneous networks of partners from different social and geographical backgrounds provide relatively rich information (according to the 'cognitive resource diversity paradigm') and increase the chances of growth and innovation (Pittaway et al. 2004; Pérez- Pérez and Sanchez 2002; Soetanto 2009). Overall, the results may indicate that, in the early years of spin-off firms, being involved in exploration and exploitation through networks increases the chances of success. However, it was also found that network diversity tends to have a negative effect on growth in highly competitive environments, pointing to the need to find a subtle balancing between networks and the founding team.

8.3.4. Spin-offs in cities in contrasting regions

> *To what extent are firm performance and external network patterns different between cities with a different location?*

The study included an analysis with regard to two cities with different types of urban location, core metropolitan versus remote, represented by Delft and Trondheim. It was consistently observed that being located in a metropolitan urban area (Delft) has a positive effect on the growth of spin-off firms. The average annual employment growth since establishment for firms in Delft was 1.74, with a standard deviation of 3.12, in contrast to an average of 0.43, with a standard deviation of 1.15, for firms in Trondheim. Moreover, of the 46 percent of firms that realized a shift to the highest category of turnover in 2010 (larger than € 500,000), 30 percent was located in Delft, and the remaining 16 percent in Trondheim (the difference was not significant for turnover). The difference is related to a better availability and higher density of additional networks and information, and other supporting factors in metropolitan regions. On the other hand, it was also consistently found that operating in a remote area tend to make firms more open towards external sources of knowledge over larger distances, particularly in an international setting, to compensate for the relative lack of information and knowledge in the local environment. Furthermore, location tends to act as an important moderating factor, for example, being located in Trondheim positively moderates the influence of absorptive capacity - through participation in training - on establishing distant knowledge relationships, as well as the influence of an enabling factor (firm size) on the level of openness of these relationships. Conversely, being located in Delft was found to positively moderate the impacts of network diversity on firm growth.

8.4. Results on propositions and a critical reflection

The propositions forwarded in Chapter 2 and examined empirically in Chapters 4 through 7 are discussed in this section. The outcomes relate to the performance of technology projects in commercialization and with growth of spin-off firms, in terms of employment and turnover. A summary of the outcomes regarding firm network features and growth is presented in Table 8.1.

8.4.1. Technology project performance

The propositions deal with the influence of the team and the network on the commercialization performance, and are based on notions from resource-based perspectives and learning theory, particularly the concept of absorptive capacity.

1.1. The performance of university-driven technology projects in bringing new technology to market is positively influenced by higher levels of absorptive capacity.
1.2. The performance of university-driven technology projects in bringing new technology to market is positively influenced by networks with large firms.

The absorptive capacity of research teams is important to scan the environment (technology, market, competitors), and select and absorb important information. Various indicators were used to measure the absorptive capacity of teams, namely, availability of project funding and accumulated knowledge in the teams through experience of the team leaders, their affinity with commercialization and the spill-over effects from parallel/predecessor projects. The efficiency level of the project, as a kind of 'realized absorptive capacity', was also taken into account. External resources were measured using one indicator, namely 'duration of collaboration with large firms'. The first proposition, regarding the absorptive capacity of a team, is partly approved among the technology projects, as (medium level) efficiency was found to be an important positive influence, whereas the affinity of the team manager with commercialization was also found to have an important impact. By contrast, external resources, represented duration of collaboration with a large firm, were observed to be relatively strong, which is in favor of the second proposition. It has to be noted, however, that the best model outcomes indicate the importance of a combination of team and network influences, namely, commercialization affinity of a team leader with collaboration with a large firm and project efficiency. This means that, in fact, the two propositions cannot be accepted as separate propositions.

8.4.2. Spinoff firm networks and growth

This subsection is devoted to two types of propositions: those concerned with the emergence of particular characteristics of knowledge networks, international reach and openness, as addressed in propositions 2.1 and 2.2, respectively, and those concerned with the growth of the spin-off firms, including the influence of team characteristics as opposed to network characteristics, addressed in proposition 3.1 (a,b) and 3.2, respectively. The results are summarized in Table 8.1.

2.1. Establishing international knowledge networks across larger distances by spin-off firms is positively influenced by higher levels of a team's absorptive capacity.

Based on theoretical views, higher levels of absorptive capacity are thought to enable a firm to recognize and acquire new external knowledge, and then assimilate that knowledge with existing knowledge and use it in its strategic choices and daily operations. This relationship was explored using two sets of absorptive capacity factors (potential absorptive capacity and realized absorptive capacity) and a set of firm-related factors. As a result, three important factors representing absorptive capacity were found significant: PhD education, participation in training, and a low level of newness. As expected, more PhDs and participation in training, as indications of a richer absorptive capacity within a firm, have a positive influence on knowledge relationships over larger distances. The results also show that low levels of newness, associated with larger distances in knowledge networking, which could be caused by existing technology solutions with a short time-to-market that the sampled firms were providing all over the world, such as in oil (energy) production, improving utilities, and engineering and software projects on site abroad, in collaboration with local customers/partners. The results are only partially in line with the propositions, because various other indicators of team absorptive capacity were found not to be important, for instance the size of the founding team and multi-disciplinarity in the education of the team members. Moreover, the influence of potential absorptive capacity on establishing long-distance knowledge collaborations, as measured in this study, tends to be stronger than that of realized absorptive capacity.

An additional result relates to the influence of control factors in building international knowledge relationships, firm size, being active in science-based industry and the ‘international market orientation’, with all have a positive effect.

> *2.2. The level of openness in knowledge networks of spin-off firms is positively influenced by higher levels of team’s absorptive capacity.*

Networks are valuable resources, specially for small technology-based firms, as they can provide access to capital, research facilities, knowledge and information, and other resources (Tether 2002; Drechsler and Natter 2012). Openness, as the dynamic ability of a firm enables to recognize, acquire and assimilate new external knowledge is a critical ability in benefiting from networks. A firm’s openness mainly develops under the influence of learning processes and the knowledge available in the founding team. In this study, openness was divided into two dimensions: *openness capacity*, including the size of the external knowledge pool, as indicated by ‘breadth’ and ‘depth’, and *openness diversity*, as indicated by the social heterogeneity of network partners, including their geographical location. A set of enabling factors, including various absorptive capacity indicators and a set of strategy factors, was used to explore the firm's level of openness. The results show the positive influence of the size of founding team on openness capacity, and of firm size, multidisciplinary of education and experience (breadth) of the founding team on openness diversity, and the strategies of being involved in a prospector strategy and in science-based innovation (only in the extended model) on openness diversity. Overall, it turned out that the absorptive capacity indicators have above all a positive influence on openness diversity.

Moreover, the results regarding openness (capacity) suggest that operating in a competitive business environment has a positive influence. In addition, the results indicate the existence of non-linear relationships, particular between firm size, pre-start experience (breadth) and prospector strategy through cubic term, and openness diversity. The results revealed a complex mechanism through which different enabling and strategy factors (absorptive capacity) influence the openness diversity dimension, which is only partially in line with the proposition.

3.1.a. Spin-off firms' performance since establishment is positively influenced by diversity in the founding team
3.1.b. Spin-off firms' performance since establishment is negatively influenced by diversity in the founding team
3.2. Spin-off firm's performance since establishment is positively influenced by diversity in the firm's network.

To examine the variation in performance (growth) among university spin-off firms, in terms of employment and turnover, since the firms started, the influence of diversity in founding teams, and in external networks, on employment and turnover was explored. The following indicators were used: diversity in education type and type of pre-start experience, and diversity in social networks and international networks. The results indicated that diversity in education type and pre-start experience type of the founders tended to have a negative effect on turnover growth, a trend that also applies to experience type and employment growth, albeit without significance. This result suggested that a high level of diversity may reduce team cohesion and create dissonance and conflict among team members, which in turn led to slower growth (Shrivastava and Rao 2010; Shrivastava and Tamvada 2011). With regard to networks, by contrast, diversity through social networks and through international networks tended to have a positive impact on growth.

The overall pattern indicated the importance of dealing with the dual objectives of exploration and exploitation outside the spin-off firm's boundaries at young ages which is in line with some emerging new insights (Simsek 2009; Lichtenthaler 2012). The results with regard to the diversity of the founding team and firm growth were not in line with the proposition 3.1.a, which is why this proposition is rejected and 3.1.b is supported, especially regarding turnover growth. By contrast, the result concerning a positive influence of diversity among network partners on firm growth is in line with proposition 3.2.

8.4.3. The influence of the type of city

The type of city is an important factor thought to influence the availability of external resources, with large cities in core metropolitan areas being better endowed, according to agglomeration theory, particularly through diversity in the urban economy, compared to smaller towns in remote areas (Jacobs 1969; Glaeser 1992; Audretsch and Feldman 1996; Capello 2006). The propositions below were explored in a basic and limited way by only including two cities (Delft in the metropolitan area of the Randstad in the Netherlands, and Trondheim in a remote area in central Norway). The propositions refer to the growth of spin-off firms (4.1) and the networks of these firms (4.2).

> *4.1. An urban location in a metropolitan area has a positive influence on a spin-off performance.*

The results of this study are partially in line with this proposition, as witnessed by the model of employment growth. Although being located in Delft was found to have a positive influence on growth, no significant effect could be observed concerning location and turnover growth.

> *4.2. An urban location in a remote area has a positive influence on a spin-off firm's level of openness and international knowledge relationships.*

Theory on learning behavior and recent empirical research (Feldman 1994; de Jong and Freel 2010; Isaksen and Onsager 2010) suggest that firms that are located in less endowed areas tend to *compensate*, in this case by being more open and operating in networks over larger distances.

As expected, it was found that firms that are located in a remote region tend to be more open towards diverse external sources of knowledge and compensate for the lack of local resources by taking part in long distance/international knowledge networks. This means that the result was in line with the proposition, although it must also be taken into account that, in a country the size of Norway, the perception of distance among firm managers is different compared to those in a small country like the Netherlands.

8.5. Conclusion on propositions and modeling results

In this section, the results of the performance models of technology projects, the results of the knowledge network models, on internationalization and openness, and the results of the firm growth models with regard to employment and turnover are discussed. A summary of the propositions and modeling results concerning spin-off firms is presented in Table 8.1. The results can be summarized as follows, starting with technology projects:

- The strength of the model of technology project performance was found to be modest. The strongest influence was the duration of collaboration with a large firm. However, all strong outcomes pointed to an important combination between this collaboration and absorptive capacity attributes, like project efficiency (medium level influence) and affinity on the part of the manager with commercialization (negative influence). Therefore, propositions 1.1 and 1.2 cannot be accepted as separate propositions.

- The internationalization model of knowledge networks was found to be relatively weak, because few absorptive capacity indicators (three) found to be important. Therefore, proposition 2.1 could not be accepted and the type of absorptive capacity factors needs to be specified.

- Of the two openness models, the diversity model was relatively strong, again with only a limited number of absorptive capacity indicators (four), with one clearly *negative* indicator (founding team size), but also with some relatively important strategy factors. In the openness capacity model, again, a few absorptive capacity factors were included, two of which had a *negative* influence (pre-start experience and firm size), while strategy factors did not appear in the best model. What was new was the positive influence of market competition. Because openness diversity behaved differently from openness capacity, and there were clear indications of non-linear relations, proposition 2.2 was found to be too broad and could not be accepted.

- In both spin-off growth models, diversity through the networks as well as the early growth strategy were found to have an important positive influence, while team (absorptive) capacity exerted a small influence, except for a *negative* one by PhD level on employment growth. A *negative* influence of diversity in education and pre-start experience type on turnover growth was found. Accordingly, proposition 3.1.a could not be accepted and 3.1.b (founding team) could be accepted regarding to turnover growth, while proposition 3.2 (networks) could be accepted.

- There were various propositions relating to urban location and growth. A urban location in a metropolitan area was found to be advantageous compared to a location in a remote area in terms of employment growth, but not with regard to turnover growth, which means that proposition 4.1 could only be partially accepted. In addition, there were also a proposition relating to urban location and network features. An urban location in a remote area was found to have an important influence (positive) in two of the three network models (the internationalization model and the openness diversity model). Proposition 4.2 could therefore be partially accepted.

A special comment ought to be made about the influence of the market (envisaged size, level of competition). By focusing on the resource-based view and learning theory, it is easy to overlook the influence of the market, which is why it was included in the analysis, and it was found to produce important trends in three situations: (1) a modest influence on the commercialization performance of technology projects, as evidenced by the *negative* influence of the combination of a small envisaged market and low affinity of the project leader with commercialization; (2) an important positive influence on building openness capacity in networks (size of external knowledge pool), indicating that spin-offs operating in a more competitive environment tend to build a larger knowledge pool (in terms of breadth and depth); (3) as a moderating effect, a *negative* influence on the relationship between diversity in network and growth, indicating that spin-off firms find it difficult to manage their external network relationships in highly competitive environments in the early years of their existence.

Table 8.1. A summary on spin-off firms' network features and growth models

	International knowledge networks	***Network openness capacity***	***Network openness diversity***	***Employment growth since establishment***	***Turnover growth since establishment***
Networks					
International knowledge networks	--	--	--	Supported (+)	Supported (+)
Local knowledge network diversity	--	--	--	Supported (+)	Supported (+)
Team absorptive capacity					
R&D expenditure	Rejected	--	--	--	--
Pre-start experience (years)	Rejected	--	--	--	--
Pre-start experience breadth	--	Rejected	Supported (+)	--	--
Pre-start experience depth	--	Supported (-)	Rejected	--	--
Education level in founding team (PhD)	Supported (+)	Rejected	Rejected	Supported (-)	Rejected
Size of founding team	Rejected	Supported (+)	Supported (-)	Rejected	Rejected
Multidisciplinary education	Rejected	Rejected	Supported (+)	Rejected	Rejected
Participation in training	Supported (+)	Rejected	Rejected	Rejected	Rejected
Newness of innovation (low level)	Supported (+)	--	--	--	--
Product development stage	Rejected	--	--	--	--
Diversity in education type	--	--	--	Rejected	Supported (-)
Diversity in experience type	--	--	--	Rejected	Supported (-)
Firm size	Supported (+)	Supported (-)	Supported (+)	Excluded	Excluded
Firm age	Excluded	Excluded	Excluded	Rejected	Supported (+)
Strategy indicators					
Ambition to grow (early strategy)	--	Rejected	Rejected	Supported (+)	Supported (+)
Market orientation	Supported (+)	--	--	--	--
Prospector strategy	--	Rejected	Supported (+)	--	--
Industry sector (innovation activity)- science-based	Supported (+)	Rejected	Supported (+) *	Rejected	Rejected
Environment					
Market competition	--	Supported(+)	Rejected	Rejected	Rejected
Location in Delft	--	--	--	Supported (+)	Rejected
Location in Trondheim	Supported (+)	Rejected	Supported (+)	--	--
N	104	105	105	105	104
R^2 or Pseudo R^2	0.17	0.20	0.53	0.34	0.14
Related propositions	2.1, 4.2	2.2, 4.2	2.2, 4.2	3.1 (a,b), 3.2, 4.1	3.1(a,b), 3.2, 4.1
Related chapters	Chapter 5	Chapter 6	Chapter 6	Chapter 7	Chapter 7

Note: Supported (+/-): means significant with positive/negative sign; Rejected: not significant in the best model or not included in the best model; (--): not taken into account in the modelling. Excluded: some variables are excluded from the models due to multi-collinearity; in these cases checks are made to avoid omitted variable bias.
*Supported in an extended model.

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Conclusions and Recommendations

9.1. Introduction

In this chapter, the main implications of the study are discussed with regard to the contribution of the study, the representativeness and limitations of the study, and suggestions for future research and policy recommendation for different stakeholders. The contribution of the study, mainly with regard to the empirical research of university-driven technology projects and university spin-off firms, is discussed in section 9.2. The resource-based view and learning theory are put into perspective in this section, by taking the influence of external resources and market characteristics into account. In addition, the contribution to theoretical views on urban innovation and empirical research is addressed. This section is followed by a discussion of the limitations of the study and by suggestions for future research, in section 9.3. Policy recommendations to various stakeholders, including management of incubators and of spin-off firms, universities, and local and regional authorities are presented in 9.4. Finally, the conclusion is presented in section 9.5.

9.2. Contribution of the study

9.2.1. Commercialization of university-driven technology projects

There are only a few studies that look at technology projects as a specific channel of knowledge commercialization by universities (Lee 2011; Kim 2013; Bozeman 2013). In fact, no literature was found on the efficiency and performance of technology projects in the context of commercialization. A trend study measuring outcomes after 10 years for older projects and 5 years for younger projects indicated that about 26 per cent of both categories of projects failed to reach the market, whereas 22 per cent of older and 15 per cent of younger projects do reach the market introduction stage. The findings of an explorative analysis indicated a strong positive influence of networking with large firms, aside from a weaker influence from team resources (absorptive capacity) which, in case of shortages, like a small affinity of the team manager with the market and a low level of efficiency, act as barriers in the commercialization process. Although the influence of a small envisaged market size was found to be weak as well, it did tend to act as a barrier. This finding relates to other barriers in the market, for instance caused by product improvements that were too small or too radical, introducing high additional manufacturing costs and, in medical fields, long testing periods (Van Geenhuizen 2013). Overall, these results are among the first of its kind in empirical studies.

With regard to theoretical viewpoints, the findings revealed a stronger importance of external resources through networks compared to team (internal) resources.

Moreover, a modest influence of market size was found. The influence of external resources and market characteristics on the performance of technology projects has a poor match with the resource-based view, with an emphasis on internal resources (Wernerfelt 1984; Barney 1991), and should therefore be a complement to the resource-based view as adopted in this study.

9.2.2. Growth of spin-off firms

The growth of small technology-based firms, particular young university spin-off firms, is a main concern in the European Union to which many studies are devoted (Mustar et al. 2006; Wright et al. 2008; Colombo and Grilli 2010). Nevertheless, there is a lack of consensus on the major determining factors and there have been inconsistent results on the influence of diversity in founding teams on the growth of young high-technology firms (Pelled 1996; Powell et al. 1996; Simsek 2009). In this study, the average annual employment growth between the start of the firm and 2010 was 1.2 fte, with a relatively high standard deviation of 2.57, indicating slow growth among many of the firms. With regard to turnover growth, 46 per cent of the firms realized a shift to the highest category in 2010 (larger than € 500,000), while 15.5 per cent had no turnover and a few had failed by 2010.

With the aim of improving our understanding of the variation in the growth of spin-off firms, this study explored the influence of capabilities in founding teams, as opposed to those gained through the external networks. The results, achieved over the lifetime of the sampled spin-offs, indicated that diversity in the founding team had a negative influence mainly on growth in turnover, which broadly confirms the notion of 'fault lines' between team members preventing them to act as an integrated unit. The barriers to growth in the sampled firms were related to different education types and different types of pre-start working experience.

By contrast, the results confirmed a positive influence of diversity in social networks (domestic) and international networks on employment and turnover growth. The implication would be that the typical combination of exploration and exploitation among young spin-off firms was better served by diversity in resources and capabilities accessed through networks outside the firm than by diversity in the resources and capabilities of the founding team. This situation is plausible, because founding teams are often composed on the basis of having a good idea and perceiving a market opportunity among friends or colleagues, while various members are replaced after some years when the need is felt for a more professional management to make the next steps in the development of the firm (Vanaelst et al. 2006; Clarysse and Moray 2004; Vohora et al. 2004). Despite the importance of networks in early years, a warning is in order, because network diversity among the sampled firms tended to negatively influence growth in highly competitive environments, a situation that required a subtle 'balancing' of firms between using knowledge of founding team members as opposed to knowledge from network partners when pressure from competition is changing. Although the subject is not unique in empirical studies, the outcomes are, particularly with regard to the influence of market competition.

The findings in this study revealed a stronger influence of diversity in firms' networks compared to diversity in firms' (internal) resources on firm growth. Moreover, this study showed that market characteristics, namely, the level of market competition, has a moderating effect on the influence of network diversity on firm growth. Accordingly, as these findings comply with those involving technology projects, from a theoretical point of view, shortcomings of resource-based view with regard to external resources (through external networks) and market characteristics need to be addressed.

9.2.3. Large distance international knowledge relationships

Building international knowledge relationships is especially important to spin-off firms if they own highly specific knowledge connecting them with a limited number of knowledge centres and customers in the world, urging them to collaborate with partners across national and continental borders. This is even more relevant to technology-based firms in small domestic economies like the Netherlands and Norway. However, crossing borders and maintaining learning relationships require specific capabilities among small firms. To prevent or overcome resource-related, cultural and institutional barriers, but also relational barriers, these firms need a well-developed absorptive capacity, allowing them to identify new knowledge and acquire and assimilate useful knowledge. The influence of barriers was clearly revealed by the sampled spin-off firms in this study, as almost 40 per cent of them have no knowledge relationships abroad.

Only a few studies were found to cover the knowledge gaps regarding the impact of absorptive capacity on establishing distant international knowledge relationships (de Jong and Freel 2010; Clercq et al. 2012; Fletcher and Harris 2012) and they used only a limited number of absorptive capacity indicators in their analysis. In this study, a whole set of indicators was explored, representing both potential and realized absorptive capacity. It was observed that a higher level of absorptive capacity, namely through higher levels of education (PhD) and market-related training, combined with a low level of newness, enhanced the establishment of distant knowledge relationships. The low level of newness referred to a particular segment of internationalized spin-offs, namely, those active in energy production, civil works and software projects across the world on the basis of technologies that were already accepted in the market. Other indicators of absorptive capacity were found not to be important among the sampled spin-offs, like R&D expenditure and the education of founding team members, in more than one discipline. The empirical contribution of this study lies in the extensive measurement and exploration of absorptive capacity, including potential and realized absorptive capacity, and a larger influence of the former, in relation to international networks, which is unique.

Taking the resource-based view and organizational learning theory into account, we expected to find a positive relationship between absorptive capacity indicators and distant knowledge relationships. However, various relationships were found not to be positive and/or significant, which could in part be due to the fact that absorptive capacity was measured indirectly through several indicators, leaving open the possibility that the results may be stronger when measuring absorptive capacity in a more direct manner. Given this situation, it is difficult to reflect on theory for this part of the study.

9.2.4. Openness in knowledge networks

Openness in knowledge relationships is increasingly being studied as an important influence in innovation and growth (Laursen and Salter 2006; Fu 2012) through which firms reduce the risks and costs of acquiring knowledge internally (Chesbrough 2003). Thus, successful firms invest in effective knowledge relationships with suppliers, sub-contractors, knowledge-intensive firms, experts/advisers, universities and research institutes, using a strategic selection and maintenance of such knowledge relationships, and thus may show different types and levels of openness (Mansury and Love 2008; Belussi et al. 2010; Dahlander and Gann 2010).

However, a knowledge gap was found with regard to open innovation among small firms, except for van de Vrande et al. (2009), Gassman et al. (2010) and Hayter (2010). This study responded to this knowledge gap by taking university spin-off firms as the subject of analysis, for which open innovation seems urgent due to a shortage of specific resources. Moreover, given a lack of understanding in existing literature of what openness constitutes in terms of main dimensions, including differences in openness between firms, openness was measured in an extended way, through two different dimensions, capacity and diversity (Barge-Gil 2010; Drechsler and Natter 2011). The sampled firms showed different scores on openness capacity and diversity, with low scores being most common. Openness capacity showed a mean score of 6.3, with a standard deviation of 3.8 and a range of 1.1 to 12.3. With regard to openness diversity, the spin-offs showed relatively low scores, as witnessed by an average of 0.35, considering a theoretical maximum score of 1.

Also, openness capacity and openness diversity were ‘driven’ by different capabilities and enabling factors. For example, firm size tended to have a different impact on openness capacity than on openness diversity, which also applied to pre-start experience in the founding team concerning depth versus breadth of experience. In addition, strategy factors, like being in the forefront of new technology (prospector) and in science-based industry (only in extended model), were found to be more important in shaping openness diversity compared to openness capacity, while openness capacity found to be directly driven by a high level of market competition and founding team size. The results regarding the factors shaping openness among spin-off firms, while distinguishing between capacity, as the size of the knowledge pool, and diversity, as diversity in knowledge partners, are a unique contribution to empirical studies.

Adopting the resource-based view and organizational learning theory, several factors were found to influence the openness of spin-off firms in their knowledge networks, while other factors, namely, education level of founding team and participation in training, were not. The results were thus only partially in line with the conceptual model, but this could be the result of existence of more complex non-linear influences, like inverted U-shaped and cubic functions. However, an exploration of these functions only found a trend of cubic functions. From a theoretical point of view, openness diversity could be well understood (relatively high model power) by factors taken from the resource-based view and learning theory. This situation did not apply for openness capacity, which, to a modest degree, could be understood by market competition. Accordingly, it can be recommended to complement resource-based view with notions from market theory, specially in describing openness capacity.

9.2.5. Type of city

Although the type of city is thought to be an important factor influencing innovative activities and growth, there are only a few empirical studies addressing differences between firms in cities in remote regions compared to core metropolitan areas, particularly with regard to openness and network distances (Isaksen and Onsager 2010). This study responded to this knowledge gap by drawing on theory on agglomeration advantages and assuming that small innovative firms in cities in a remote region require more openness and more knowledge from distant sources, to compensate for deficiencies in their local environment. Taking a limited compensation through networks into account, firms in remote cities were also assumed to experience lower growth rates, related to less diversity in the labor market of knowledge workers, absence of launching customers, etc., as compared with firms in large metropolitan areas (Audretsch and Feldman 1996; Capello 2006; Gordon and McCann 2000).

In line with these arguments, it was found that firms in Trondheim tended to establish knowledge relationships across larger distances and worldwide, and they were more likely to be open in terms of connecting with diverse partners. However, no influence on openness capacity was identified. Moreover, the results confirmed a positive influence of being located in Delft, a core metropolitan area, on employment growth (although not on turnover growth). In addition, being located in a large metropolitan area tended to reinforce the positive impact of diversity through networks on firm growth, as indicated by a positive moderating influence of being located in Delft on the impact of knowledge networks on growth. Overall, this study contributes to empirical studies by being among the first to reveal trends whereby firms compensate for a lack of local resources through knowledge networks.

Taking urban innovation views into account, the results largely confirmed the agglomeration advantages of firms being located in large metropolitan areas facilitating a stronger growth (employment) there, whereas the results also confirmed a compensation for local resource deficiency among firms in remote cities, causing them to connect with diverse national and international partners. These findings contribute to theory about firm behavior (strategies of compensation) in relation to different degrees of agglomeration.

9.3. Limitations and suggestions for future research

9.3.1. Representativeness

The data used in this study came from two previous studies, namely, Soetanto (2009) and van Geenhuizen (2011). The first data set was ‘updated’ as far as the growth of spin-off firms was concerned, by including the size of the spin-offs in 2010 with regard to employment and turnover. The fact that existing data were used sometimes limited the scope of this study to some extent.

With regard to university-driven technology projects, the trend study made use of data covering both technical and general universities in two parts of the Netherlands, namely, the West and Southeast of the country, including different technologies, and included young projects (started early 2000) and older projects (started since 1990). It is believed that the results of the trend study are representative of technology projects in similar urbanized parts in European countries with identical institutional and structural mechanisms in financing university-driven technology projects. Projects in the in-depth study were mostly drawn from the trend-study database, albeit for only a limited number of technologies, which made the in-depth study less representative, but still valuable as an explorative study for selected technology domains. Moreover, the study is an elaboration of data provided by Technology Foundation STW, and the projects involved went through a selection procedure for investment by this foundation. This may mean that the representativeness of the technology projects was limited by the selection criteria of STW, but, as previously indicated, many of those projects also gained financial support along other ways, thereby broadening the representativeness of the university-driven technology projects in the study.

In studying spin-off firms, data from two technical universities in Europe, Delft University of Technology in The Netherlands and NTNU in Norway, were pooled. Those universities were selected from 40 incubators in the world. It is believed that the results of the study on these firms are representative for other university spin-offs of technical universities in Europe, especially the ones located in countries with small open economies and an orientation towards sea-based economic activity, and a relatively risk-averse entrepreneurship culture (GEM 2010) and an innovation profile that identifies them as followers according to the European Innovation Scoreboard (ProInno Europe 2011).

In this study, university spin-offs were conceptualized as a sub-category of new technology-based firms (Chapter 2), however, the results of the study cannot be extended to include all categories of technology-based firms. While the study included relatively young spin-offs (between 4 and 14 years in 2010), the results with regard to establishing knowledge relationships, openness strategy and growth may only fit this younger category of firms. As firms become older, they are better able to manage their internal resources and their external networks, which means that diversity in the team make-up may be beneficial at later stages of firm development. More importantly, spin-off firms from technical universities may only be representative for those segments of young technology-based firms that have a technical origin and face a lack of market and marketing knowledge and skills, which may limit their ability to overcome barriers in establishing networks, which may not be the case with, for example, young corporate spin-off firms.

In addition, the youngest ‘generation’ of spin-offs, established between 2006 and 2010, could not be included in the study. This means that the results are only valid for somewhat older spin-off firms, particularly those established in years when the crisis was not as long-lasting as it is today.

9.3.2. Limitations and suggestions for further research

While the study has produced some new and rich results on the performance of technology projects and growth of spin-off firms, various limitations became apparent in the course of the research that could be prevented in future studies.

Additional data, measurement and sample size

In the sample of university-driven technology projects, due to data limitations and the nature of technology projects, some variables were studied at a low level of measurement, for example the available financial capital. In research practice, there is formal and informal collaboration between projects, and knowledge may easily flow into a project from different sources of finance. Future research could investigate the efficiency and performance of technology projects in larger samples with richer data, taking the limitations of data collection for technology projects into account, for instance derived from the ‘fluidity’ of knowledge. Moreover, some additional influencing factors, including the structure of institutions, may play a role in university-industry relationship that could be taken into account in future studies (Perkmann and Walsch 2007). Using larger samples, future studies may apply stronger techniques in identifying, for example, non-linear relationships.

There were some general drawbacks to this study, due to the small sample of spin-offs and the available data, limiting the selection of variables in the modeling of international knowledge relationships, openness in knowledge relationships and overall growth among spin-off firms. In the part of the study on spin-off growth, due to the small sample and data limitations, several important factors, like industry sector, level of newness of innovation of the product/process, the stage of product/process development and network characteristics like centrality (Simsek et al. 2009) were excluded from the analysis.

Moreover, due to data limitations regarding openness, it was not possible to clearly distinguish between the inflow and outflow of knowledge and collaborative learning (co-creation), and the different types within these categories for spin-off firms. Thus, it would be interesting to include specific inflow modes in future research, such as licenses and formal agreements on the delivery of knowledge and outflow modes, like marketing agreements with large firms, to better describe the openness and open innovation concepts.

With regard to measurement issues, several variables were explored in this study using proxies, for instance absorptive capacity. In future research, attempts should be made to move from using proxies to a more direct measurement of absorptive capacity, while not yet identified aspects of absorptive capacity should be included as well, for instance concerning knowledge assimilation, preferably also measured directly. There were also some limitations with regard to the city of location and the cities involved in the networks. Firstly, the urban location included only two contrasting regions. However, it would be interesting to extend the number of cities based on the type of region, for instance by including a city in a region with a medium level of remoteness in a European context, for example, Enschede in the Netherlands. Secondly, due to reluctance among the people we interviewed, for reasons of confidentiality, various data were measured as a binary or in broad size-classes. International knowledge relationships were measured as a binary variable, while richer data may include the name of cities of the partners involved. This information was, however, not revealed by managers of spin-offs for the reasons mentioned above, particular when large companies were involved. Similarly, questions on turnover caused large non-response if precise amounts were included, which meant that turnover could only be measured using size-classes. In future research, attempts need to be made to find alternative ways like website analysis for cities in networks to obtain more accurate data.

And finally, the network characteristics were measured using an ego-centric approach, with a maximum of the five closest partners, which meant that no information was provided about other partners that are less important in knowledge interaction. As a check revealed that 80 percent of the respondents mentioned only four partners, it is less likely that the data lacks significant information in this sense, which is why the limitation to five partners cannot be seen as a weakness.

A longitudinal approach

Cross-section data were used on founding team characteristics and the shape of networks, which implied that changes in absorptive capacity, due to adjustments in the management team, were excluded, while literature indicates relevant changes (Murovec and Prodan 2009; Bishop et al. 2011). Future research could enhance the results of this study by adopting a longitudinal approach. For example, it would be interesting to study the spatial reach in networks, to take the dynamics in the founding team, in terms of size and diversity in disciplines, into account in future research. Also, it would be interesting to study openness in networks, and to take the dynamics of openness into account, because there are indications in literature that openness changes with the age of the firm (Laursen and Salter 2006; Chesbrough 2006). Overall, management teams may change over time, in terms of age, experience and education, and the shape and openness of the networks may evolve over time, depending on the need to access external resources changes. Therefore, a longitudinal study would yield a better description of the effect of team and network diversity on firm growth (Vanaelst et al. 2006; Jansen et al. 2009).

9.4. Policy recommendations

In the policy recommendations in this section, four types of stakeholders are distinguished: the management of incubators (or incubation programs), managers of university spin-offs themselves, universities, and local and regional governments dealing with the regional innovation system (RIS). The focus is on providing recommendations with regard to spin-offs and technology projects in Delft or technical universities in similar locations.

9.4.1. Management of incubators and of spin-off firms

In Chapter 7, it was found that it is mainly the network in the early years that enhances the growth of spin-off firms, which is echoed in other studies involving young firms (Larson and Starr 1992; Grant 1997; Powell et al. 1996; Johansson et al. 2005; Walter et al. 2006). The *diversity* in networks, regarding the types of socio-economic partners and regions, specially in terms of transcending the region, was found to have a positive influence on employment growth. In contrast to the positive impact of network diversity, diversity in the starting team tended to have a negative effect on growth, both in terms of diversity in education and of experience type, apparently leading to fault lines within the team. These observations lead to three recommendations:

- Prevent having a high level of diversity in the starting team with regard to education and type of pre-start working experience, because diversity appears to be an obstacle to taking adequate decisions. After the first years, there is often a natural move towards a more professional composition of the team.

- Increase the socio-economic diversity of the network partners, e.g. with launching customers and financial institutes, as well as spatial diversity, the latter including partners abroad. Networking beyond the own, personal, circle presents many obstacles for young spin-off firms, like a lack of knowledge about the best partners and on how to trust them (IP matters), and a lack of the resources needed to manage advantageous networks. In Delft, 40 percent of the spin-off firms did not have international networks. Accordingly, it would be helpful if the incubator program provides coaching in effective networking and in overcoming barriers, particularly in internationalization, and develop best practices (see, e.g. van Geenhuizen and Ye 2013).

- While increasing network diversity, the managers of spin-off firm and incubators need to be aware of the trend that, in a turbulent business environment with strong market competition, diversity in the networks needs to be limited.

Further recommendation can be drawn from the analysis of internationalization (Chapter 5) and of openness in socio-economic networks (Chapter 6). Firm size and science-based innovation (learning) tend to exert a positive influence, both on openness in relations (diversity) and on international knowledge relationships, while there are also differences: education level (PhD) and participation in training do not enhance firms' openness in relations, but they do enhance establishing networks abroad. Moreover, the level of innovative activity plays a role in enhancing internationalization, whereby low levels of innovativeness tend to enhance internationalization. These considerations lead to the following recommendations:

- Naturally, firm size and science-based innovation cannot be used as an 'instrument' to increase openness in social-economic networks and to increase internationalization, but the lack of capacity and skills involved can be compensated by searching for networking expertise, e.g. through customized training and external specialists.

- By contrast, to enhance internationalization, it would be helpful to include a PhD in the founding team. However, as previously indicated, a PhD should not substantially increase the diversity in the team, as this tends to impede team integration and growth. This would imply that the knowledge/skills of a PhD in acting internationally need to be achieved in another way, as suggested in the previous point, through customized training and external specialists.

The recommendations presented above are not meant as a 'one-size fits all' solution for spin-offs. As became apparent in the previous chapters, factors that enhanced (international) networking indicated differences in firm size (age), the level of innovative activity and sector (science-based and otherwise), although not all three factors point into the same direction. Age is an important differentiating factor, not only because of overlap in influence with firm size, but also because young firms are eligible for incubation support.

In Delft, the annual job growth of spin-off firms was 0.6 fte in the first four years, whereas among older ones, job growth increased to 2.6 fte on average per year. Thus, firm growth in the early years calls for attention. Considerations in this study, as well as in its predecessor study (Soetanto 2009) and other studies (van Geenhuizen and Soetanto 2009), point to four 'stylized types' of spin-off firms, each requiring a different approach in local support:

1. Young, high or low level of innovative activity, not internationalized and relatively closed networks, with a slow growth.
2. Young and older ones, low innovative with a product/service in the market, often active internationally, for instance in consulting, civil engineering work, and energy activity, with a quick growth.
3. Older ones, highly innovative and possibly active in science-based sectors, often international and learning through open networks, with a quick growth.
4. Older ones, possibly in the process of falling back to consultancy, not internationalized, relatively closed networks, with a slow growth.

Given its slow growth, type 1 should be eligible for additional support, in addition to standard support from the incubator (program), aimed at escaping the cycle of 'being small, not able to network effectively, and remaining small', through learning from best practices among their colleagues and from customized courses. With regard to type 4, support should aim at a 'through start', in which open learning networks and international networks are actively being stimulated and shaped in 'connecting sessions'. Training experience and case-study research (van Geenhuizen and Ye 2013) teach us that having a small set of different key partner(s) is crucial, rather than having a large number of different partners, for example a venture capitalist that provides access to other networks and invests in further growth, a city authority that enables a pilot test through which the design of the product can be better adapted to practical needs, an intermediary agent in China who knows the best local suppliers and acts according to local customs, thereby decreasing risks, and an innovative partner for co-creation through which risks in development are shared and time-to-market may be shortened, particularly if this partner is a launching customer.

9.4.2. University

The management of university incubators may use different policies to enhance the process of spinning-off new ventures: the low selective, the supportive and the incubator approach (Clarysse et al. 2005). Based on these different models, there are various resource implications, relating to finance, organization, human resources, technology, network and infrastructure in managing the process. Each of these models focuses on promoting different types of spin-offs, while drawing on the regional innovation system (RIS) in different ways. For example, the supportive model relies heavily on the interface with the regional environment to be successful, including sufficient contacts with local experts, business entrepreneurs and specialized consultants. The policy of Delft University of Technology can be qualified as hybrid of supportive and incubator approaches located in a well-developed fabric of networks and contacts that were built up in the past years, which, according to the results of this study, reinforces the positive impact of open knowledge networks (diversity) on growth.

Nevertheless, there are three missing elements in the region of Delft University of Technology as identified in another study (van Geenhuizen 2013). Firstly, there is a slight ‘mismatch’ with the regional economy, evident in the lack of large mechatronics and medical technology industry in the region; secondly, there is no regional development agency providing location subsidy and ‘soft’ venture capital, which are present in other regions; and, thirdly, there is a shortage of cheap but representative accommodations for spin-offs leaving the incubator Yes!Delft, which has caused various spin-offs to leave the region, particularly to move to the Province of North-Brabant (Eindhoven area). Although the circumstances outlined above cannot be changed overnight, currently, a regional development agency is being established (Province of South-Holland) and incubator accommodations are being extended.

One point remains, however, for both spin-off firms and university-driven technology projects: various inventions that originated at Delft University of Technology are facing a relatively poor ‘seed bed’ in the region in terms of the presence of a matching manufacturing sector. Attracting a variety of manufacturing firms or subsidiaries to the region is not easy, especially not during an economic crisis, but what could be done is to organize specific open innovation arrangements at the university, in which selected large manufacturing firms from elsewhere can connect in so-called test-labs and become involved in certain parts of university research and development, including R&D conducted by spin-off firms. Of course, in such arrangements, rules on intellectual property (IP) need to be established. Such initiatives already exist on a small scale, but they need to be an integral part of the university network interaction that fits into a broader orientation of the university on the commercialization of knowledge, and connects with a set of other recommendations, as indicated below. This mainly applies to science faculties at general universities.

Various in-depth results on technology projects in this study may help improve the support of technology projects initiated at universities, for which four recommendations can be made (again, addressed in particular at general universities):

- Learning how to build and maintain relationships with large firms can be taken as part of courses on commercialization at universities, including attention to the major barriers in these relationships, namely different time lines, unexpected strategic shifts by companies, different attitudes towards intellectual property (IP), etc. (Bjerregaard 2010; Bruneel et al. 2010; Gilsing et al. 2011; van Geenhuizen 2013).
- A low affinity among particular project managers with commercialization can be taken into account in allocation models at university, meaning that funding for applied research with market potential is preferably granted to research teams (managers) that regard commercialization as their primary mission.
- Substantial career incentives for commercialization and a separate tenure track for researchers faced with a high profile in this activity can be provided (van Praag et al. 2011; van Geenhuizen 2013), to attract and retain more researchers at university with a strong market affinity. At technical universities, attracting part-time professors from industry (‘dual appointments’) is already a common practice in this context.
- A conscious policy needs to be developed at universities as to what types of new product/processes to bring to market, to create a *balanced* composition of inventions, including those that are ‘appealing’ and close to the market, alongside those that have a long way to go in commercialization.

9.4.3. Local and regional authorities

Local and regional authorities in the Netherlands see their role in enhancing commercialization of university knowledge often as that of facilitator in creating essential conditions in the regional innovation system. In the case of Delft, this is clearly evidenced in a partial financing of the university incubator. In addition, there is the policy of creating meeting places and enhancing a lively cultural life, in which the link with technology as well as global relationships are nicely reflected and used in creating a local ‘tissue’ of networks and actors.

Cities and regions (provinces) can, however, be more (pro-) active and take the lead, thereby eventually also acting as a manager of public-private initiatives connected to knowledge commercialization. The following roles can be mentioned as directly and indirectly enhancing the commercialization of university knowledge which are relatively new:

- *Directly*: cities as initiators and together with universities and financial banks as actors in the supply of venture capital, like Amsterdam and Rotterdam in life sciences; cities as drivers of pilot testing in their area, thereby initiating experimentation and learning about practical applications of new technology; cities as drivers or participants in 'living labs', where they, together with end-users (or lead-users), large and small firms, including spin-offs and the university, create conditions for co-creation, and cities as launching customers, in-so-far this is possible given limitations due to regulation.

- *Indirectly*: cities as drivers of and participants in active Triple Helix or Quadruple Helix constellations, thereby enhancing universities, the business world, user-groups (lead-users) and themselves to cross borders and actively collaborate and align initiatives; cities as connectors with higher level authorities (e.g. EU) in efforts to increase (research) budgets both to be spent at university research and to be spend in the regional innovation system to improve particular shortcomings; cities as drivers of and - together with universities and business actors - as governors of regional networks and platforms, to which spin-off firms can connect for local networking in the case of Delft, for example, Medical Delta.

9.5. Conclusion

This chapter included a reflection on theory, specially the resource-based view of firms, learning theory and views on urban innovation. It also addressed the contribution of the study of which the empirical ones are the strongest. The following trends can be mentioned:

- The larger role of networks on the performance of technology projects and spin-off firms compared to capabilities and skills in the team, and the intermediating role of competition in the market.
- The positive influence of ambitious growth strategy on the performance of spin-off firms.
- The positive influence of firm size and science-based activity in enhancing the openness (diversity) and internationalization of knowledge networks.
- The stronger networking activity (openness and international) among spin-offs in remote places, to compensate for shortcomings in local assets.

In addition, some limitations of the study and several suggestions for future research were discussed. Finally, various policy implications were addressed to different stakeholders: management of incubators, managers of spin-offs, university and local/regional authorities.

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Appendix A – Questionnaires on spin-off firms (used in 2006)

1. Firm profile

Year and city/municipality where the firm started *(Registered at the Chamber of Commerce)*		……………. year …………… City
Year	At the time of the start	
Number of employees including founder(s)	….… (fte)	…… ……..
Number of R&D employees including the founder(s)	….… (fte)	……. ……..
Based on your ambition about your business expansion, what was the objective of your firm	☐ Become a big firm with international orientation ☐ Small with local orientation ☐ Small with international orientation ☐ others: ……………………	
Current situation of your company (in terms of business activities)	☐ Grows rapidly ☐ Grows ☐ Stable ☐ Shrinks ☐ Re-grows ☐ Other : ………	
Annual turnover in the last year (Euro)	☐ < 100.000 ☐ 100.000-300.000 ☐ >300.000 ☐ No turnover	
Source of turnover : (please give the indication of their percentage from total turnover)	☐ Selling products - percentage…….. % ☐ Consultation - percentage…….. % ☐ Development and design - percentage…….. % ☐ Others : ………………. - percentage…….. %	
Have you experienced growth in **(current situation)** a)	☐ Turnover ☐ Network ☐ market position ☐ Others : …………	
Did you have own R&D	(Yes/No)	
Average annual spending on R&D over the last three years (percentage from turnover) :	……. %	
If no turnover yet, which source of capital used to finance your R&D activities, please mention the other sources:	☐ Subsidies/grant ☐ Own money ☐ ………	
Please describe the main product/service of your company (e.g. software, instruments, coatings, etc)		
Is the main product/service a breakthrough *(radically new)* ?	(Yes/No)	
Is the main product/service of your company "new to the sector"? *(meaning: not introduced previously by a competitor)*	(Yes/No)	
Is the product based on a patent (owned / license)	(Yes/No)	
Is your product/service a market leader?	(Yes/No)	
Do you have many competitors with the same product or service?	No	
What is your firm's most significant market? a) (future market)	(Yes/No)	
What is your firm's most significant market? a) (future market)	☐ Local/regional *(within a distance of around 30 minutes by car)* ☐ National *(with a distance of more than 30 minutes by car)* ☐ International ☐ Others …………	
Please describe your current activities (e.g. pilot production, testing, routine manufacturing, standard service, redesign product, marketing, etc)		
Do you have any plans for business expansion in future?	(Yes/No)	
If Yes, expansion is in :	☐ R&D investment ☐ Routine production ☐ Pilot production ☐ Marketing expansion ☐ Others: small series….	

a) *Multiple answers are possible;* b) *Please tick the correct class;* c) *Circle the right answer*

2. Entrepreneurs' team profile (starting team)

		1^{st} Founder	2^{nd} Founder	3^{rd} Founder	4^{th} Founder
Educational background	Degree (e.g. BSc, MSc, PhD, etc)				
	Discipline (e.g. electronics, business, chemistry, etc)				
Age when starting up firm (year)					
Have the founders experience in **starting a new firm?** If Yes, when? (years) Have the founders got **working** experience before starting a new company? If Yes, what experience : [a] 1. Research experience 2. Managerial experience 3. Other : finance If Yes, how long? (years) If Yes, is the previous job or started firm in the same sector as the current firm?		(Yes/No) [c] ………. (Yes/No) [c] ☐ ☐ ………… ……….. (Yes/No) [c]	(Yes/No) [c] ………… (Yes/No) [c] ☐ ☐ ………… ………… (Yes/No) [c]	(Yes/No) [c] …………….. (Yes/No) [c] ☐ ☐ …………… …………… (Yes/No) [c]	(Yes/No) [c] ………… (Yes/No) [c] ☐ ☐ ………… ………… (Yes/No) [c]

3. Most entrepreneurs discuss from time to time about important issues with others, for example with family, friends, colleagues, etc. Please indicate up to five (5) important partners (not employed by your firm) from whom you received **information and knowledge**. (For instance: advice on managing business, finding investment, competition, new ideas on product development, open new market opportunities, connect to new customers or suppliers, etc)

Person	1	2	3	4	5
Initial					
How long have you known in person? (years)					
How well do you know the person? 1. Very well 2. Somehow 3. Very little	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐	☐ ☐ ☐
How did you get into contact with the person? 1. Own contact 2. Referred by other person in personal network 3. Referred by other person in university network 4. Referred by other person in business network 5. Other : ………………………	☐ ☐ ☐ ☐	☐ ☐ ☐ ☐	☐ ☐ ☐ ☐	☐ ☐ ☐ ☐	☐ ☐ ☐ ☐
How many times in a month (on average) did you have a conversation *face to face* with this 'person' about your business?					
How long does it take to reach this 'person' by car? (Travel time)					
City (of partner)					
Is he/she [a)] 1. A senior executive of firm with a high reputation 2. An officer at a high level of the government 3. A professor at a university 4. Owner of other small business (shareholder in Smart Motor) 5. Family or friend Other :	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐	☐ ☐ ☐ ☐ ☐

What are you discussing and what types of information and knowledge do you receive?					
Person #	1	2	3	4	5
Information or contact about new market / customer	☐	☐	☐	☐	☐
Information about competitors and industrial trends	☐	☐	☐	☐	☐
Managerial advice in managing the new firm	☐	☐	☐	☐	☐
Organization issues and human resources development	☐	☐	☐	☐	☐
Technological advice	☐	☐	☐	☐	☐
Product and service development	☐	☐	☐	☐	☐
Research facilities, equipment and testing	☐	☐	☐	☐	☐
Cooperation and partnership with other firms	☐	☐	☐	☐	☐
Legal aspects (e.g. patent, tax, etc)	☐	☐	☐	☐	☐
Financial-related information (e.g. loan, venture capital, etc)	☐	☐	☐	☐	☐
Others :					

4. Think about the relationship between the five people you named above. For each pair, indicate the relationship between these 2 people as far as you know.

	Stranger	Somewhat acquainted	Well acquainted (know each other very well)	Not Sure
Persons (1) and (2)	☐	☐	☐	☐
Persons (1) and (3)	☐	☐	☐	☐
Persons (1) and (4)	☐	☐	☐	☐
Persons (1) and (5)	☐	☐	☐	☐
Persons (2) and (3)	☐	☐	☐	☐
Persons (2) and (4)	☐	☐	☐	☐
Persons (2) and (5)	☐	☐	☐	☐
Persons (3) and (4)	☐	☐	☐	☐
Persons (3) and (5)	☐	☐	☐	☐
Persons (4) and (5)	☐	☐	☐	☐

5. There are many **sources of information and knowledge** located nearby or at a distance from your firm that satisfy the firm's needs. From your experience, please assess their importance to your growth. In the last column, we ask you to mention the location of the most important contributor to your firm's knowledge.

Source of knowledge	Have this relationship?	Located in Delft and surrounding *(within a distance of around 30 minutes by car)*					Located outside Delft and surrounding *(with a distance of more than 30 minutes by car)*					Location of the most important source of knowledge (City)
		Strongly Unimportant	Unimportant	Moderate	Important	Strongly Important	Strongly Unimportant	Unimportant	Moderate	Important	Strongly Important	
		1	2	3	4	5	1	2	3	4	5	
Technical university	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
General university	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
College/institutes of vocational training	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Government's research center	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Commercial laboratories /R&D enterprises	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Customers (Clients)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Suppliers (e.g. parts, materials)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Competitors	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Other firms from the same industry	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Firms located in incubator or enterprise group	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Chambers of commerce	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Trade organizations	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Consultants	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Exhibitions / fairs	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Internet	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	
Other ………………	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	

A short questionnaire on spin-off firms* (used in 2010)

Firm name …..

1. Total number of employees (end of 2010): fte
2. Annual turnover in 2010: ☐ no turnover yet
   ☐ < 100.000 ☐ 100.000 – 300.000 ☐ 300.000 - 500.000 ☐ >500.000
   (please tick the correct class)
3. Which major events has the firm experienced in the past five years? (multiple answers possible)
   ☐ market introduction of new product/process, etc, year …….
   ☐ merged with or acquired by other firm; year ….. : …………..
   ☐ radical shift to another product or market; year ……………..
   ☐ other major event, namely …………..………………………..
   (multiple answers possible)

   * Part of the data on knowledge sources and growth of the firms, including employment and turnover, was measured at two points in time, 2006 and 2010, the last through a short mail questionnaire, supplemented by website analysis.

Appendix B – Questionnaire on university-driven technology projects (list of points discussed on technology projects with project managers)

NICIS Commercialization of University Driven Technology Projects (2009-2010)

Introduction

- Name project leader, position, university, region
- Type of project leader (rewards in science and applied research)**
- Years of experience of the project leader in the current research group
- Name STW project
- Position of STW project (previous or adjacent project, or standalone project)
- Other major financing aside from STW

Invention profile

- Type of innovation (radical/incremental)
- Type of technology (domain)
- Starting year of commercialization (first structured thinking on market introduction and how to reach it)
- Year of first important development results
- Year of first important patent application
- Year of first important cooperation with market party (large firm)
- Year of establishment of spin-off firm
- Year of (foreseen) market introduction
- Current situation in relation to market introduction

Market profile

- Type of envisaged market and customers (medical, energy, etc.)
- Envisaged market size
- Strength of regulation

Manager's Satisfaction/Opinion

- Satisfaction of manager with commercialization results (scale of 1-10) and background to this satisfaction
- Affinity of manager with commercialization
- Hampering and enhancing factors (internal/external), including region

** Data were supplemented by website analysis.

Summary

The commercialization of university knowledge has gained increased attention among researchers and policy-makers in the past 10 years and today is fully recognized as the third mission of universities[1]. Bringing university knowledge to the market to create economic value is done first of all through education and graduates becoming active in the labor market, but also through various other channels, including patenting and licensing, technology projects at universities in collaboration with industry and the creation of university spin-off firms. Also, there are various modes that are less structured, like conference presentations and incidental consultancy commissioned by industry. At the moment, some of these channels lack effectiveness, as addressed in European literature in the recent past, for instance with regard to the growth of university spin-off firms.

This study shed light on the performance of university-driven technology projects and university spin-off firms, and on the underlying mechanisms of these two channels. Accordingly, the study belongs to the mainstream of “start-up firm growth” and “high-technology small firms” and “knowledge transfer or commercialization performance”, by taking the role of internal resources and networks of firms and research teams into account.

Firstly, the concept of knowledge commercialization was introduced and the research questions elaborated in Chapter 1. In Chapter 2, the theoretical perspectives used in the study were discussed, including the resource-based view of firms, organizational learning theory and views on urban innovation. A set of related concepts, including absorptive capacity, knowledge networks, diversity in founding teams and diversity in networks, were elaborated to better understand the behavior of spin-off firms in establishing knowledge relationships, nationally/internationally and the degree of openness, to better understand their growth. Furthermore, in Chapter 2, various propositions were forwarded, to be investigated in the empirical chapters (4 to 7) and the summary of results is in Chapter 8.

With regard to university-driven technology projects, two data sets were used, a sample of about 370 projects derived from Technology Foundation (STW) in the Netherlands in a trend study encompassing various years, and a sample of 42

[1] Knowledge commercialization is also called knowledge valorization in the Netherlands, which, in broad terms, includes the commercial and non-commercial utilization of knowledge, through economic and social value creation. Knowledge valorization is defined by the Rathenau Institute (NL) as the process of value creation from new knowledge by adapting this knowledge and making it available for economic and/or social utilization and translating it into competitive products, services, processes and/or newly established firms. We have used the term knowledge commercialization throughout the study, because the term is more common in English literature.

representative projects in an in-depth study of trends. With regard to university spin-offs, a sample of 105 spin-off firms was used derived from two technical universities, Delft University of Technology in the Netherlands and NTNU in Norway. Chapter 3 contained a characterization of the databases. In addition, the methods of analysis used in the various chapters were explained and the main concepts of the study were operationalized in broad terms. Details regarding indicators, and the way each indicator was measured, were presented in the empirical Chapters 4 to 7.

In Chapter 4, the focus was on the performance of university-driven technology projects in terms of commercialization and on the factors underlying this performance. The study applied data envelop analysis, followed by rough-set analysis, to examine the efficiency of technology projects in terms of commercialization outcomes, respectively. Results with regard to the efficiency were derived from an examination of inputs relative to outputs in the process. The most efficient projects were found to be the ones with a limited number of years of collaboration with large firms, a limited use of financial investment capital, and relatively large advantages from predecessor and adjacent projects. Furthermore, with regard to the commercialization results, a combination of network-related factors and the absorptive capacity of research team members were found to be important: years of network collaboration with large firms, efficiency of the projects, and affinity of the project leader with commercialization. Accordingly, the commercialization results tended to be more favorable on the basis of a longstanding collaborative relationship with a large firm and medium-level efficiency. Conversely, the chance of failure was high if the project leader had little affinity with commercialization and the envisaged market for the innovation was limited. Being located in one of the regions in the Netherlands (the Randstad region or the Southeast, or a combination of the two) was found to have no influence.

Chapters 5, 6 and 7 were concerned with university spin-off firms, in particular the capability of their starting teams (absorptive capacity) and networks (internationalization and openness), and their growth. In Chapter 5, the influence of the absorptive capacity of the spin-offs on distant knowledge relationships was explored, using a distinction between potential absorptive capacity and actual absorptive capacity. Generally speaking, potential absorptive capacity tends to have a stronger influence on establishing international knowledge relationships compared to actual absorptive capacity. In particular, a positive influence was found with regard to the education level of founders (number of PhDs) and their participation in market-related training. Remarkably, a low level of newness tended to positively influence knowledge relationships over large distances, which could be explained by the activity of a relatively large share of spin-offs at long distances abroad, in energy production, the construction of infrastructure works and large ICT projects. Overall, the power of the internationalization models was found to be relatively weak, as in some previous studies, which is why it was recommended to measure absorptive capacity more directly in future studies.

Chapter 6 focused on the openness of spin-offs in knowledge relationships. The level of openness was measured using two dimensions, i.e. capacity and diversity, and the underlying factors were explored. Using two sets of factors - enabling factors (absorptive capacity related) and strategy-related factors - the results tended to confirm that the breadth of pre-start experience of founders, multidisciplinary education, firm size, and two strategy-related factors - adoption of a prospector strategy and science-based innovation activity (only in extended model) - enhance the dimension of partner diversity. A strong market competition and larger teams at the start tended to encourage firms to search for various knowledge types relatively deep (openness capacity dimension). The strongest influence of absorptive capacity related factors was found for openness diversity, and the model involved was relatively powerful compared to the openness capacity model.

Finally, in Chapter 7, the growth of spin-off firms was the core subject, with special attention to the influence of the founding team at the start and the firms' networks. The study revealed that network diversity, through (domestic) social networks and international networks tend to positively influence employment and turnover growth since the start. However, a negative influence was found for education and experience type diversity among founders on turnover growth, which indicated that young start-ups are better able to balance their explorative and exploitative activities through diverse networks compared to their internal diversities, the latter causing a lack of team coherence and, most probably, a delay in making important decisions. However, networks tend to negatively influence growth in highly competitive environments. In addition, the early growth strategy was found to have a positive influence on firm growth.

In Chapter 8, the research questions were answered and the results of testing the propositions were discussed. This included the performance models of technology projects, the knowledge network models concerning internationalization and openness, and the results of the growth models for employment and turnover. The strength of the models of the performance of technology projects was found to be relatively weak, with the influence of the duration of collaboration with a large firm being the relatively strongest factor. In the internationalization model of knowledge networks, three absorptive capacity indicators were found to be important, placing an emphasis on the role of team resources on establishing long-distance relationships, but overall the model was relatively weak. By contrast, the openness model was relatively strong, and the similarity with the internationalization model was related to the importance of various absorptive capacity indicators. In the spin-off firm growth models, which were reasonably strong, the influence of the networks was found to be more important than the influence of the founding teams.

In each spin-off model, attention was also paid to the influence of the region where the city is located, divided into two categories, namely metropolitan (core) and remote in Europe, represented by Delft (NL) and Trondheim (Norway), respectively. Spin-offs in metropolitan areas tended to grow more quickly compared to their counterparts in remote areas, with regard to employment, but not with regard to turnover growth, which may suggest the presence of specific labor market shortages in remote cities, and also a 'compensation' for such shortages by spin-offs through their networks. Two out of three network models indicated that a remote location enhances the establishment of network relationships.

In all models, attention was also paid to the influence of the market, in terms of the envisaged size of the market and market competition. Overall, market influence tended to be a relatively weak factor, in technology project performance and in building openness capacity by spin-off firms. However, it had a negative impact on the positive influence of network diversity on spin-off growth.

And finally, in Chapter 9, the contribution of the study was evaluated. The strongest contributions can be summarized as follows. Firstly, the exploration of 'commercialization lines' of technology projects was the first in its kind in empirical research. The contribution to theory was in the emphasis of networks with large firms, as a complement to resource-based view; the same was true for spin-off firm growth, with a stronger dependency on networks compared to the internal capacities of the teams. This pattern implies that, in the commercialization of knowledge, typically surrounded by high levels of uncertainty, access to lacking resources is mainly provided by networks, as clearly indicated by previous studies. Secondly, in the study of long distance (international) knowledge relationships, absorptive capacity was measured on a detailed level, which made the study rather unique as an empirical study. With regard to the contribution to learning theory, the stronger explanatory power of potential absorptive capacity, compared to that of actual absorptive capacity, is worth mentioning. Overall, the explanatory power was small, which may be due to the indirect way of measuring.

Thirdly, in the study of openness in knowledge relationships, the distinction between capacity (size of the knowledge pool) and diversity (partners) is a rather unique contribution to empirical research in the context of open innovation. Theoretically, it is important to mention that the two dimensions have clearly different underlying factors, market-related factors for capacity and absorptive capacity (learning theory) factors for diversity. Moreover, market factors (competition) have a moderating influence on the external acquisition of resources. This calls for a somewhat stronger emphasis on the role of the market when using resource-based view analyzing openness capacity. And, fourthly, spin-off growth in remote cities seems to be associated with 'compensation behavior', using networks to access resources. This situation implies that a relatively poor urban environment doesn't always matter, because local shortages may be mitigated by the strategy of the firm. This 'behavioral' component could be better articulated in views on urban innovation and growth.

The focus in Chapter 9 was also on various limitations of the study and implications for future research. The limitations can be summarized as follows: the relatively small size of the samples as a constraint for the size of the models; the ‘given’ databases from earlier studies, in which particular variables were sometimes missing and others were just indicators, measuring characteristics and intentions indirectly; the cross-section character of the data, while networks and teams tended to change by time/age. Also, the ‘urban dimension’ has been included in the study to a limited degree, namely, only on the basis of two cities. All these limitations can be taken as challenges for future research, with the implication of a significant additional effort in data collection.

Finally, various practical implications of the results were forwarded, and addressed to three different stakeholders in a general way: incubators and the spin-off firms themselves, universities and local/regional authorities. With regard to the incubators, it is recommended to discourage spin-offs to create a high level of diversity within the starting team; in contrast, diversity in networks, including international knowledge relationships, could be enhanced through customized coaching provided by the incubator, with special attention to markets that are characterized by high levels of competition. Establishing international knowledge relationships can also be enhanced by advising spin-offs to include PhDs in the founding team, except when that creates a high level of diversity within the starting team.

With regard to universities, commercialization along the two channels examined in this study can be enhanced by providing courses on entrepreneurship, which often already exist, and on business strategy, marketing strategy and market dynamics, to improve insight among university researchers into the behaviour of potential business partners. Also, it is recommended to allocate grants to university researchers with a high affinity for commercialization and markets. The latter recommendation fits into a broader policy to create a fully recognized ‘position’ for commercialization research, including enhancing careers in this area and developing separate ‘tenure tracks’. Another way to reinforce the position of knowledge commercialization at universities is to increase the number of ‘dual appointments’, meaning part-time chairs for researchers from industry, which is already a common practice at technical universities. Commercialization of knowledge at university may also benefit from a conscious development of ‘commercialization portfolios’ including a combination of projects that can be brought to market quickly and projects that take a longer time, depending, among other things, on the newness of the inventions and tightness of regulation.

With regard to local/regional authorities, the study provides arguments for a more active involvement in creating favourable conditions for the commercialization of knowledge. In order to shorten ‘commercialization lines’ and create more knowledge about the size and character of future markets, local/regional authorities may enhance the establishment of local pilots and ‘living labs’, with the active participation of user groups, and act as ‘launching customer’ within their given limits.

Samenvatting

Het commercialiseren van universitaire kennis is de afgelopen tien jaar steeds sterker in de belangstelling komen te staan van onderzoekers en beleidsmakers en wordt momenteel aan vele Europese universiteiten erkend als de zogenaamde derde missie, naast onderwijs en onderzoek. Het naar de markt brengen, of ruimer genomen, het economisch en sociaal benutten van kennis door universiteiten[2] verloopt via verschillende kanalen, traditioneel via afgestudeerden die de arbeidsmarkt betreden, en hiernaast via het verkopen of in licentie uitgeven van octrooien aan bedrijven, opdrachtonderzoek aan de universiteit of gemeenschappelijk onderzoek van bedrijven met universiteit, universitaire spin-off bedrijven en hiernaast nog een aantal andere, minder gestructureerde vormen, zoals conferenties en incidentele adviesopdrachten aan de universiteit. Van enkele nieuwere kanalen wordt in de Europese literatuur gesteld dat deze weinig effectief zijn, in het bijzonder groeit het merendeel van universitaire spin-off bedrijven langzaam.

Het onderwerp van deze PhD studie is commercialisatie van kennis afkomstig van universiteiten, de resultaten ervan en de eraan ten grondslag liggende factoren en processen. De focus ligt hierbij op twee kanalen van commercialisatie, namelijk universiteit-gedreven technologieprojecten en universitaire spin-off bedrijven. De studie valt onder de mainstream van ‘groei van technologie-gebaseerde starters en kleine bedrijven’ en ‘performance van kennisvalorisatie’, waarbij bijzondere aandacht is besteed aan ‘interne’ eigenschappen van teams (onderzoeksteams en startersteams) en eigenschappen van externe netwerken gericht op kennis, zowel met een nationale als internationale oriëntatie.

In Hoofdstuk 1 is het thema van kenniscommercialisatie geïntroduceerd en zijn probleemstelling en uitgewerkte vragen uiteengezet. De theoretische invalshoeken van de studie zijn omschreven in Hoofdstuk 2, met bijzondere aandacht voor de ‘resource-based view, leertheorie voor organisaties en stedelijke innovatietheorie. Een reeks hiermee samenhangende concepten is eveneens naar voren gebracht, zoals absorptiecapaciteit en team diversiteit, en hun belang is beargumenteerd in het verklaren van de eigenschappen van spin-offs’ netwerken, landelijk en internationaal. Ook is de invloed van netwerken en van teams op de groei van spin-

[2] In Nederland wordt in toenemende mate de term kennisvalorisatie gebruikt. Strikt genomen gaat het hierbij om commercieel benutten maar ook om niet-commercieel benutten van kennis, dus om economische en maatschappelijke waarde creatie. Kennisvalorisatie wordt door het Rathenau instituut omschreven als het proces van waarde creatie uit kennis, door kennis geschikt en/of beschikbaar te maken voor economische en/of maatschappelijke benutting en te vertalen in concurrerende producten, diensten, processen en nieuwe bedrijvigheid. In deze samenvatting gebruiken we de term commercialisatie overeenkomstig de Engelstalige hoofdtekst maar doelen hiermee op de ruimere betekenis.

off bedrijven en resultaten van technologieprojecten onderzocht. In Hoofdstuk 2 zijn ook verschillende ‘proposities’ gepresenteerd en deze zijn in de hierna volgende hoofdstukken onderzocht met gebruikmaking van twee datasets van universiteit-gedreven technologieprojecten, één van bijna 370 projecten met diverse uitkomsten van de commercialisatielijn en één van 42 representatieve projecten met resultaten van achterliggende oorzaken, en met gebruikmaking van een database van spin-off bedrijven, 105 in totaal, in de leeftijd van 1 tot 10 jaar tijdens de eerste dataverzameling in 2006/7.

In Hoofdstuk 3 zijn de databases nader gekarakteriseerd en de onderzoeksopzet en methodologie tegen het licht gehouden. Ook is in dit hoofdstuk uitgelegd hoe de diverse kernconcepten in grote lijn meetbaar zijn gemaakt in de hiernavolgende empirische hoofdstukken (4 tot en met 7). Zo is openheid in kennisrelaties geoperationaliseerd en gemeten met behulp van de indicatoren ‘openheid capaciteit’ en ‘openheid diversiteit’. Details over de indicatoren zijn opgenomen in de individuele hoofdstukken.

Hoofdstuk 4 is gewijd aan de performance van universiteit-gedreven technologieprojecten en aan de factoren die hieraan ten grondslag liggen. Data-envelop analyse en rough-set analysis zijn gebruikt om grip te krijgen op achtereenvolgens de efficiency van deze projecten en het bereikte resultaat in de ‘commercialisatielijn’. De analyse van efficiency is gebaseerd op de verhouding tussen inputs en resultaten (output), waarbij de meest efficiënte projecten gekenmerkt werden door een klein aantal jaren samenwerking met grote bedrijven, inzet van beperkte financiële middelen en voordelen van een voorafgaand of simultaan project. Het bereikte commercialisatie resultaat kon worden teruggevoerd op een samenspel tussen netwerkfactoren en absorptiecapaciteit van het onderzoeksteam. Commercialisatie tendeerde gunstiger uit te pakken, in de zin van snelle marktintroductie, bij een langdurige samenwerking met een groot bedrijf, een middelmatige efficiency en een sterke affiniteit van de teamleider met commercialisatie. De kans op een mislukking was groter naarmate de markt die men voor ogen had, kleiner was.

Hoofdstuk 5, 6 en 7 zijn gewijd aan spin-off bedrijven, hun teamcapaciteit (absorptievermogen), kennisnetwerken (openheid) en groei. In Hoofdstuk 5 stond de invloed centraal van absorptievermogen van het startersteam op het aangaan van kennisrelaties over lange afstand en hierbij werd onderscheid gemaakt naar het potentiële en gerealiseerde absorptievermogen. Als tendens is naar voren gekomen dat het potentiële absorptievermogen belangrijker is voor internationale kennisrelaties dan het gerealiseerde absorptievermogen. Het ging vooral om positieve invloed van PhDs in het startersteam en om deelname van teamleden aan marktgerichte training. Opmerkelijk was eveneens de trend van een positieve invloed van een laag innovatieniveau op internationale kennisrelaties. De verklaring lag in het relatief grote aantal spin-offs die in het buitenland actief zijn in energiewinning, aanleg van infrastructuur en grote ICT projecten. Aangezien de verklaringskracht van de modellen relatief beperkt was, werd aanbevolen om absorptievermogen in de toekomst meer direct te meten.

Het thema van Hoofdstuk 6 was open innovatie in de zin van open kennisrelaties, waarbij opnieuw de invloed van absorptievermogen van het startersteam werd onderzocht, naast andere factoren. Openheid werd uiteengelegd in twee dimensies, te weten, capaciteit als de omvang van de kennispool en diversiteit als de sociaaleconomische samenstelling van de kennispartners, inclusief locatie van de partners. Factoren die tenderen openheid qua diversiteit te beïnvloeden zijn pre-start ervaring en multidisciplinariteit in de opleiding (oprichters), omvang van het bedrijf en – als twee strategie-gerelateerde factoren - actief zijn als ‘voorloper’ en actief zijn in science-based innovatie. De meest positieve invloed van absorptievermogen werd aangetroffen wat betreft de dimensie diversiteit en het betreffende model had ook een grotere verklaringskracht vergeleken met de dimensie capaciteit.

Tenslotte stond groei van de spin-off bedrijven centraal in Hoofdstuk 7, met een studie van de invloed van het startersteam en van de netwerken op deze groei. De resultaten wezen op een positieve invloed van diversiteit in de netwerken, nationaal en internationaal, zowel voor aantal banen als omzet van de bedrijven; dit in tegenstelling tot een negatieve invloed van twee indicatoren van absorptievermogen (team), namelijk diversiteit in opleiding en in pre-start ervaring (alleen wat betreft omzet). Deze patronen zouden kunnen wijzen op gebrek aan samenhang in het startersteam als gevolg van diversiteit en hiermee op tekort aan slagvaardigheid. Mogelijk kunnen relatief jonge spin-offs beter exploratie en exploitatie op elkaar afstemmen en groeien door gebruik te maken van de mogelijkheden van diversiteit in het netwerk en is diversiteit binnen het startersteam in deze fase lastig om mee om te gaan.

In Hoofdstuk 8 werden de onderzoeksvragen beknopt beantwoord en de eerder geformuleerde ’proposities’ onderzocht. Dit betrof commercialisatie uitkomsten van technologieprojecten, netwerken van spin-off bedrijven en groei van deze bedrijven. Het schattingsmodel voor technologieprojecten bleek relatief zwak te zijn, met als enige sterke invloed de duur van samenwerking met een groot bedrijf. In het netwerk model voor internationale kennisrelaties bleken enkele factoren van het absorptievermogen (team) van belang te zijn, dit gold ook voor het model van open kennisrelaties wat betreft diversiteit. Hiernaast was dit laatste model relatief sterk.

In elk model werd ook aandacht besteed aan de regionale ligging van de stad, dit uitgesplitst naar grootstedelijke (metropool) en geïsoleerde stad aan de rand van Europa, respectievelijk Delft in Nederland en Trondheim in Noorwegen. Spin-offs in een grootstedelijk gebied tendeerden sneller te groeien wat betreft aantal banen, echter niet wat betreft omzet. Dit zou kunnen wijzen op specifieke arbeidsmarkt tekorten in geïsoleerd gelegen steden en op ‘compensatie’ van dit soort lokale tekorten door desbetreffende bedrijven via hun netwerken met meer centrale steden. Twee van de drie netwerkmodellen toonden aanwijzingen dat een geïsoleerde ligging het aangaan van netwerkrelaties in de hand werkt.

In elk model is eveneens aandacht besteed aan relevante invloeden van de markt, zoals de voorziene omvang van de markt en de mate van concurrentie. Over het geheel kwamen marktinvloeden niet naar voren als dominant. Voor het welslagen van technologieprojecten was het een zwakke invloed. De markt speelde eveneens een bescheiden rol in de omvang van de kennispool bij spin-off bedrijven. Hiernaast werden aanwijzingen gevonden voor een negatieve invloed van de markt op de relatie tussen diversiteit in open netwerken en groei. Een relatief sterke concurrentie zou de positieve invloed van netwerkdiversiteit op de groei te niet doen.

In Hoofdstuk 9 is op een rij gezet wat de bijdrage van dit dissertation is geweest aan theorie en empirisch onderzoek. De volgende onderdelen konden als sterk worden aangemerkt. Ten eerste, de resultaten van de technologieprojecten (commercialisatielijn) waren de eerste in hun soort in empirisch onderzoek. De theoretische bijdrage lag in het naar voren komen van het belang van netwerken, dat niet geheel strookt met uitgangspunten van de ‘resource-based view’. Een soortgelijke conclusie was ook mogelijk op basis van de groei van spin-off bedrijven; zij lijken meer te drijven op netwerken dan op de interne capaciteiten van het team. Dit betekent dat in commercialisatie van kennis - omgeven als deze is met grote onzekerheid - blijkbaar netwerken de toegang tot benodigde resources bieden en dit zou in de ‘resource-based view’ beter gearticuleerd kunnen worden. Ten tweede, in de studie van internationale kennisrelaties van spin-off bedrijven is absorptievermogen op gedetailleerd niveau gemeten en dit maakte de studie betrekkelijk uniek. Gelet op de theoretische bijdrage is de wat grotere verklaringskracht van potentiële ten opzichte van gerealiseerde absorptievermogen vermeldenswaardig. Over het geheel genomen is de verklaringskracht van de modellen vrij zwak, hetgeen ook veroorzaakt kan zijn door de indirecte meting van absorptievermogen.

Ten derde, in de studie naar open kennisrelaties van spin-off bedrijven is het onderscheid naar de capaciteit (diepte) van de kennispool en diversiteit in partners een unieke empirische bijdrage. Theoretisch gezien is de tendens van belang dat de twee dimensies door verschillende factoren worden beïnvloed, capaciteit door marktfactoren (concurrentie) en diversiteit door factoren ontleend aan de ‘resource-based view’ en leertheorie van organisaties. Marktfactoren (concurrentie) kunnen hiernaast een modererende invloed hebben op het effect van de inbreng van resources, hetgeen eveneens in de ‘resource-based view’ beter gearticuleerd kan worden. Ten vierde, groei van spin-off bedrijven in perifeer gelegen steden leek geassocieerd te kunnen worden met ‘compensatie’ op basis van netwerken die elders toegang verschaffen tot lokaal ontbrekende resources. Deze situatie wijst erop dat de ruimtelijke omgeving voor de bedrijfsgroei meer een context is dan een bepalende factor en dat lokale tekorten kunnen worden aangevuld door middel van een bepaalde bedrijfsstrategie. Deze gedragscomponent zou in stedelijke innovatietheorie meer kunnen worden benadrukt.

In Hoofdstuk 9 zijn ook enkele beperkingen van de studie belicht: de relatief kleine omvang van de steekproeven die een uitgebreide modellering (modelomvang) in de weg stond, waardoor bepaalde factoren buiten beschouwing moesten blijven; de gegeven databestanden - opgebouwd in eerder onderzoek- die niet altijd volledig waren gelet op de gewenste data; het gebruik van alleen cross-sectie data, groei uitgezonderd, terwijl teams en netwerken van jonge bedrijven kunnen veranderen met leeftijd/tijd. Ook zijn in de studie veelal indirecte gegevens gebruikt als indicatoren voor bepaalde eigenschappen en intenties van bedrijven, zoals absorptievermogen van het startersteam en strategische redenen om open kennisrelaties aan te gaan, terwijl deze ook meer direct gemeten hadden kunnen worden. Tenslotte is de stedelijke dimensie in de studie beperkt gemeten, met twee contrasterende steden. Stuk voor stuk vormen deze beperkingen interessante uitdagingen in vervolgonderzoek, op voorwaarde van een aanmerkelijke uitbreiding van de databestanden.

Tenslotte zijn ook een aantal implicaties voor beleid naar voren gebracht, waarbij een driedeling in stakeholders is gemaakt tussen management van incubators (en van bedrijven), de universiteit en de lokale/regionale overheid, en de aanbevelingen generiek van karakter zijn. Wat betreft incubators (en de bedrijven zelf), het is vanwege invloed op de bedrijfsgroei nodig om te adviseren de diversiteit binnen het startersteam beperkt te houden, dit gelet op opleidingsniveau en werkervaring. In netwerkvorming is het daarentegen aanbevelingswaardig om meer diversiteit aan te brengen tussen de partners en dit zou door middel van coaching door de incubator (of gerelateerd instituut) kunnen worden gestimuleerd. Dit geldt vooral voor markten met een sterke concurrentie. Diversiteit in dit verband gaat niet over zoveel mogelijk verschillende partners maar over enkele selecte partners met diverse strategische posities ten opzichte van verbonden netwerken. In het bijzonder is het aangaan van kenniscontacten in het buitenland belangrijk voor de groei, dit kan worden gestimuleerd door meer PhDs op te nemen in het startersteam omdat zij vaak al ervaring hebben in het buitenland, waarbij – gelet op het voorgaande - een grote diversiteit in het startersteam moet worden vermeden.

Wat betreft universiteiten, het versnellen van commercialisatie langs de twee bestudeerde kanalen kan worden bevorderd door medewerkers en afgestudeerden beter voor te bereiden op ondernemerschap en samenwerking met grote bedrijven. Dit door middel van doelgerichte training waarbij inzicht wordt gegeven en vaardigheden worden aangekweekt op het vlak van business strategie, marketing en marktdynamiek. Hiernaast zou toegepast onderzoek met grote commercialisatie potentie vooral moeten worden verricht door onderzoekers met duidelijke affiniteit met commercialisatie. Dit hangt samen met een breder streven om voor commercialisatie een eigen plaats op de universiteit te creëren, namelijk door carrière stimulansen te geven aan onderzoekers die zich voornamelijk met commercialisatie bezighouden en voor hen afzonderlijke 'tenure tracks' te ontwikkelen. Een andere manier om de plaats van commercialisatie op de universiteit te versterken is de 'duale benoeming' van parttime hoogleraren uit het bedrijfsleven, hetgeen op technische universiteiten al gebruikelijk is. Een eigen plaats voor commercialisatie op de universiteit kan hiernaast ook baat hebben bij het opzetten van een doelbewuste portfolio van verschillende typen projecten, zoals gebaseerd op fase ten opzichte van marktintroductie (meer fundamenteel versus meer toegepast en dicht bij de markt) maar ook op mate van regelgeving, bijvoorbeeld in experimenten en bij toelating tot de markt.

Tenslotte, voor lokale/regionale overheden zijn de volgende aanbevelingen uit dit onderzoek naar voren gekomen. Lokale/regionale overheden kunnen zich meer actief opstellen in het verbeteren van een aantal voor commercialisatie noodzakelijke voorwaarden. Om commercialisatie lijnen te kunnen bekorten en begrip aan te kweken over de omvang en aard van toekomstige markten, kunnen lokale/regionale overheden het oprichten van lokale pilotstudies en 'living labs' met actieve deelname van gebruikersgroepen stimuleren, en kunnen zij ook optreden als 'launching customer'.

Acknowledgements

The PhD research that was started five years ago has been finalized by publishing this thesis. I found this period quite valuable through which I developed my capabilities and learned to be a more patient and devoted person in research. I would like to take this opportunity to thank the people who contributed to my development directly and indirectly and the ones who made this work comes true.

First, I would like to thank Delft Center for Entrepreneurship (DCE) and Netherlands Institute for City Innovation Studies (NICIS) for financial support of this project.

Next and foremost, I would like to thank my promoter, Prof. Marina van Geenhuizen, for all the energy and time she put into my work. Her valuable advices and criticisms guided my research journey. I would also like to thank all the members of the examination committee for their valuable comments and suggestions.

I would like to thank all my former colleagues at DCE specially in the first year of my PhD with whom I found myself in a creative environment. Special thanks go to Boukje Vastbinder, Esther Blom, Joan Tijtra, Leonie Ridderstap, Lianne Sleebos, Martine van Veelen, Susan Tate, Umer Wasim and Wouter Meyers. I would also like to thank all the colleagues at Technology and Innovation department. Many thanks go to Helen Keasberry and El Arkesteijn-van Schaik for their helpful attitude, Alfred Kleinknecht, Cees van Beers and John Groenewegen for their valuable advices and to Zenlin Kwee, Roland Ortt, Adriana Diaz Arias, Pablo Bortz, Claire Stolwijk, Ardalan Haghighi Talab, Jafar Rezaei, Geerten van de Kaa, Fardad Zand, Caludia Werker, Fernao Beekens, Laurens Rook, Hanieh Khodaei, Victor Scholten, Patrick van der Duin, Elisa Anggraeni, Prap Suprapto, Mohammadbashir Sedighi, Sergey Filippov, and Marian Bosch-Rekveldt for their warm personalities.

During my course of research, I had the privilege of co-supervising several master students like Sake Smith, Qing Ye (Cum laude), Helmi Fadilah and Teun Blik. I highly enjoyed our cooperation and constructive discussions and talks.

Finally, I would like to dedicate this work to very special ones in my life: to my dear parents, Molook and Ali, who devoted their life to my development, dared me to experience and supported me to follow my dreams. I am very grateful to both of them for any achievement in my life; to my two lovely brothers, with whom I grew up and learnt a lot and to Peyman for his kindness and support.

Mozhdeh Taheri,
Delft, October 2013

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Mozhdeh Taheri was born in Iran. She achieved her Bachelor Diploma from Amirkabir University of Technology (Tehran Polytechnic) in Industrial Engineering - planning and system analysis in December 2000. To extend her academic experiences and knowledge, and after one year working experience as an engineer in monitoring of power plant projects in Iran, she decided to move to the Netherlands and study a Master in Systems engineering, policy analysis and management (SEPA) at Delft University of Technology. She received a full scholarship for the two year study at TU Delft and graduated in 2004. Her thesis dealt with a cross-national study of cost overrun of large-scale transportation projects. Looking for new opportunities in industry, she went back to Iran and started her career in the planning and budgeting department of a private holding company in December 2004. Soon after, she became a top-level manager and a member of the board in this company. In October 2008, looking for a step forward in her career and her personal interest in innovation management and technology based entrepreneurship, she came back to the Netherlands and started as a PhD researcher. During her time of research at TU Delft she was involved in as a complementary member of the commission and a supervisor of 4 Master students and assisted in teaching courses in the area of regional economics, high-tech marketing and quantitative research methods in management of technology research. Moreover, she assisted in organizing workshops in coaching entrepreneurs, supported by Spin-Up Project within EU Lifelong Learning Programme. Her research interests covers knowledge commercialization, knowledge networks, systems of innovation, innovation management and organizational learning. She has published her research in several conference proceedings, book chapters, and journals. She has been personally interested and involved in entrepreneurial activities and projects bridging theoretical knowledge and market applications since 2006 with the focus on three areas of academic, green and women entrepreneurship in Iran and she hopes to develop her activities in these areas.

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There is no happiness except in the realization
that we have accomplished something

--Henry Ford