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STUDIES ON THE DIFFUSION OF NEW SCIENCE-BASED TECHNOLOGIES

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ABSTRACT

Technological change is one of the key driving forces behind economic growth. In this process, the diffusion of new technologies plays a vital role. In particular, the early stages of diffusion, in which knowledge is created and transferred for wider industrial use, are seen as crucial to the broader societal impact of technologies. Therefore, it is essential to understand how technologies diffuse from academia to industry, and to highlight different factors that facilitate or hinder the diffusion process. This thesis addresses the diffusion of nanotechnology and biotechnology in four articles, each highlighting a specific and critical part of the early-stage diffusion process.

The first article focuses on the variety of outcomes that university researchers achieve when interacting with companies. It identifies whether a researcher's boundary-spanning position in research collaboration networks is connected with these outcomes. The results suggest that university-industry interaction leads to both tangible and intangible outcomes and that boundary-spanning plays a role in achieving them.

The second article highlights the importance of understanding the unique characteristics of the transferred technology. It compares the specificities of nanotechnology to other science-based technologies such as biotechnology. The empirical results indicate that nanotechnology differs from other science-based technologies in only a few dimensions of technology transfer related to the basic research orientation of nanotechnology.

The third article emphasises the role of smaller technology-dedicated companies in the diffusion process. The paper highlights the importance of understanding the economic value of the patent portfolio of biotechnology-dedicated companies with respect to the companies' future growth expectations. The results indicate that there exists a positive connection between growth expectations and the value of patent portfolios; this value could be signalled to external financiers.

The fourth article identifies links between smaller technology-dedicated companies and larger established companies. The latter may act as industrialists when introducing new science-based products and processes to the market. The results of this paper identify several potential diffusion channels for nanotechnology in both traditional and high-tech industries.

The articles provide implications for research, policy and practice. The key implications relate to the role of interdisciplinarity as an important ingredient in producing more industry related knowledge, the technology specificity of the technology transfer process and the different roles smaller and larger companies have in technology diffusion.

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TIIVISTELMÄ

Teknologinen muutos on eräs taloudellisen kasvun avaintekijöistä. Tähän muutokseen liittyy keskeisesti uusien teknologioiden diffuusio. Erityisesti diffuusion ensivaihe, jolloin tieto luodaan ja siirretään teolliseen hyödynnettäväksi, on kriittinen tekijä teknologioiden laajemmassa yhteiskunnallisessa vaikuttavuudessa. Täten on erityisen tärkeää ymmärtää kuinka uudet teknologiat leviävät akatemiasta yrityksiin ja korostaa tekijöitä, jotka edistävät tai haittaavat diffuusiota. Tässä väitöskirjassa käsitellään nanoteknologian ja bioteknologian diffuusiota neljän artikkelin kautta, joista kukin korostaa tiettyä kriittistä vaihetta teknologioiden diffuusioprosessissa.

Väitöskirjan ensimmäinen artikkeli keskittyy akateemisten tutkijoiden yritysyhteistyöstä aikaansaamiin tuloksiin. Tarkastelussa on erityisesti tutkijoiden asema tutkimusyhteistyöverkostoissa ja miten keskeinen asema verkostoissa liittyy edellä mainittujen tuloksien saavuttamiseen. Tulokset antavat ymmärtää, että yritysyhteistyö liittyy niin aineellisiin kuin myös aineettomiin tuloksiin. Lisäksi keskeinen asema tutkimusyhteistyöverkostoissa on tilastollisesti merkitsevä tekijä saavutettaessa kyseisiä tuloksia.

Toinen artikkeli korostaa siirrettävän teknologian erikoispiirteiden merkitystä keskusteltaessa teknologian siirtymisestä akatemiasta yrityksiin. Artikkelissa vertaillaan nanoteknologian erityispiirteitä muihin tiedelähtöisiin teknologioihin, kuten bioteknologiaan. Tulokset osoittavat, että nanoteknologia eroaa vain muutamassa teknologiansiirron ulottuvuudessa, jotka liittyvät nanoteknologian perustutkimukselliseen luonteeseen.

Kolmas artikkeli painottaa pienten teknologiayritysten merkitystä diffuusioprosessissa. Artikkelissa korostetaan bioteknologia-alan yritysten patenttien taloudellisen arvon suhdetta heidän arvioihinsa yrityksensä tulevaisuuden kasvusta. Tulokset viittaavat siihen, että on olemassa positiivinen yhteys patenttien taloudellisen arvon ja yritysten kasvuodotusten välillä, mikä voidaan viestittää muun muassa ulkopuolisille rahoittajille.

Neljäs artikkeli tunnistaa teknologisia yhtäläisyyksiä pienempien teknologiayritysten ja suurempien yritysten välillä. Nämä suuremmat yritykset voivat toimia kaupallistajina uusiin tiedelähtöisiin teknologioihin pohjautuvia tuotteita ja prosesseja markkinoille tuotaessa. Artikkelin tulokset viittaavat siihen, että nanoteknologialla on useita mahdollisia kaupallistamiskanavia niin perinteisillä kuin myös korkean teknologian toimialoilla.

Väitöskirjan artikkeleiden pohjalta voidaan vetää johtopäätöksiä tutkimukselle, julkiselle päätöksen teolle ja yrityksille. Keskeisimmät johtopäätökset liittyvät poikkitieteellisyyden rooliin yrityksille mielenkiintoisen tiedon tuottamisessa, teknologioiden erilaisten luonteiden huomioimiseen liittyen teknologiansiirtoon, sekä pienten ja suurten yritysten erilaisiin rooleihin teknologioiden diffuusiossa.

Asiasanat diffuusio, tiedelähtöiset teknologiat, nanoteknologia, bioteknologia	
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Foreword

$$\sim(\exists r : \exists s : (P(r,s) \wedge (s = g(sub(f_2(y))))))$$

– Gödel, 1931

This dissertation has benefited from the support of a great variety of people both directly and indirectly. I wish to thank my supervisor Professor Markku Maula who has provided invaluable support, particularly during the last stages of the writing process. His insightful comments have helped me to overcome the challenges that emerged while finishing this dissertation. I also wish to acknowledge the very insightful remarks made by the pre-examiners of the dissertation, Professor Patrick Llerena and Professor Aldo Geuna. In addition, I thank Annaleena Parhankangas and Heli Koski for their support in the early stages of the dissertation process.

This dissertation could not have been completed without the support and contributions of the co-authors of two of the dissertation articles. Christopher Palmberg was the person who first hired me to ETLA. I am greatly indebted to him for launching my career as a researcher. His enthusiasm and willingness to explore new research areas and methods have been inspiring. Raine Hermans and Martti Kulvik are the co-authors of my first ever published article. Their patience with my first steps in the world of academic publishing allowed me to get acquainted with the revise and resubmit process. The lessons learned have proven to be more than useful in the later stages of writing this dissertation.

This dissertation would not have come into existence without the support and flexibility of Pekka Ylä-Anttila and Petri Rouvinen. They have provided me with a vibrant and motivating work environment that has provided me with the opportunity to work on a variety of interesting topics and the freedom to take time off to work on academic endeavors related to this dissertation. I also wish to acknowledge the important role that my colleagues at the ETLA community have played in creating this dissertation. Antti Tahvanainen has commented on many of the drafts versions of the dissertations articles, for which I am very grateful, and has provided excellent entertainment both in and outside the office. Mika Pajarinen has given solid data and programming guidance whenever requested, and I am grateful for the many weeks of work that he has saved me by showing ways to manage data efficiently. Jyrki Ali-Yrkkö, Matthias Deschryvere, Annu Kotiranta, Olli Martikainen and Timo Seppälä have all made my work days more than enjoyable. In addition, I am grateful to the rest of the staff of ETLA for their various ways of contributing to this dissertation.

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Writing this dissertation would not have been possible without the kind support from various funders. I wish to acknowledge the funding by Tekes, Technology Industry's Centennial Foundation, Instrumentarium Science Foundation, Foundation for Economic Education, Yrjö Uitto Foundation, Helsingin Sanomat Centennial Foundation and The Finnish Doctoral Program in Industrial Engineering and Management.

While the work and academic environments have been important to writing this dissertation, the support and role of family have been essential in reaching this goal. My inspiration in life is my mother Liisa. Her guidance has proved invaluable not only when growing up but also later in life when important decisions needed to be made. I wish to thank my sister Sirje and her family, Mika and Jesse, my father Harri, my two aunts Tuire and Sessa, and my late grandmother Ingeborg for having a keen interest towards my efforts. In addition, my in-laws Hanna, Antti, Olli and Niina have all supported my writing by constantly asking when to bring out the banderols. Also, my dear friends Hannes, Jani, Palmu, Tomppa, Vili, Vipe, Marika and Ville have all helped in various ways along the long path often reminding me of the realities of life.

Lastly, but most importantly, I am ever grateful to my wife Laura for her unconditional support during the last years. She has understood my work much better than most other people, including a variety of academics. Her encouragements have provided the last crucial ingredients that I needed to finish this chapter in my life. This dissertation would not have been possible without you. I love you more than words can express.

Working on this dissertation has been an exercise that has taught me humility, patience and endurance. I hope to maintain these attributes in my future work as well as in everyday life.

Helsinki, April 2010

Tuomo Nikulainen

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List of publications

This dissertation consists of a summary article and the following papers:

1. Nikulainen, T. (2010): "The outcomes of individual level technology transfer and the role of research collaboration networks", ETLA Discussion paper nr. 1214.

   (An earlier version of the paper entitled "What makes a gatekeeper? Insights from the Finnish Nano-community" was published in the DRUID Working Paper Series nr. 07-03, 2007).

2. Nikulainen, T. and Palmberg, C. (2010): "Transferring Science-based Technologies to Industry – Does Nanotechnology Make a Difference?", Technovation Vol. 30 (1), pp. 3-11.

   Contributions: Based on the original concept of Nikulainen and Palmberg. Nikulainen had the main responsibility for building the analytical framework, statistical analyses, data management and reporting.

3. Nikulainen, T., Kulvik, M. and Hermans, R. (2008): "Patent citations indicating present value of the biotechnology business", International Journal of Innovation and Technology Management, Vol. 5 (3), pp. 279-301.

   Contributions: Based on the original concept of Nikulainen, Kulvik and Hermans. Nikulainen had the main responsibility for building the analytical framework, statistical analyses, data management and reporting.

4. Nikulainen, T. (2010): "Identifying nanotechnological linkages in the Finnish economy – An explorative study", Technology Assessment & Strategic Management, Vol. 22 (5), pp. 513–531.

INTRODUCTION TO THE DISSERTATION

1 Background

New technologies go through several different stages of diffusion before they are widely applied and used (Abernathy and Clark, 1985; Dosi and Nelson, 2009). This process typically involves several actors, namely, public sector research, companies and government bodies, all of which play distinct roles in the different stages of diffusion (Bozeman, 2000; Siegel, 2007). Some of the most critical stages of diffusion, particularly in relation to science-based technologies, are the initial stages wherein the underlying knowledge and the technologies built on it are created and then transferred from the research-orientated academic realm to the commercially-orientated corporate realm (Gibbons et al., 1994).

Technology diffusion and particularly technology transfer from academia to industry have been topics of interest in recent decades as the role of public research activities conducted in universities and public research institutes has come to be perceived as increasingly important in creating new processes and products (Gibbons et al., 1994; Mowery and Sampat, 2004). In particular, the extant literature has focused on highlighting the incentives for companies, universities, university departments, and university technology transfer offices to engage in technology transfer-related activities (for reviews, see Bozeman, 2000; Rothaermel et al., 2007; Siegel, 2007). To provide a complementary and a more micro-level perspective, the incentives for individual university researchers to be involved in technology transfer have become a topic of increasing interest among scholars in recent years (Agrawal and Henderson, 2000; Louis et al., 2001; Brennenraedts et al., 2006; Balconi and Laboranti, 2006; D'Este and Patel, 2007; D'Este and Perkmann, 2007; Palmberg, 2008; Perkmann and Walsh, 2009; Boardman and Ponomariov, 2009; Perkmann, 2009). Despite the extent of research on technology transfer, there is considerable room for more research on the role of knowledge creation and the technological specificities of technology transfer.

As technologies and the underlying knowledge spillover from academia to industry, different types of companies have various roles in facilitating the diffusion process. On the one hand, smaller technology-dedicated companies are more capable of mastering radical, discontinuous technologies but face uncertainties related to, among other things, funding (Tushman and Anderson, 1986; Meyer, 2005; Teece, 2006; Rothaermel and Thursby, 2007). On the other hand, larger established companies are more adept at utilising their existing knowledge in mastering more incremental technologies, but they may play a critical role in the diffusion of radical technologies. Larger companies may have complementary assets, such as manufacturing and marketing expertise, that smaller companies often lack, providing larger companies with competitive advantage over the smaller entrants (Teece, 1986 and 2006; Mitchell, 1989 and 1991; Hill and Rothaermel, 2003; Rothaermel and Hill, 2005; Rothaermel and Boeker, 2008). While the prior research has extensively examined the different roles of companies in the diffusion process, the literature on modern science-based technologies and particularly on nanotechnology is scant, leaving room for contributions.

To understand the early and critical stages of technology diffusion in greater detail, this PhD dissertation addresses factors related to individual-level involvement in technology transfer and discusses the different roles and challenges of companies in the subsequent stages of the diffusion process. The perspectives at both the individual researcher's level and the company level are highlighted to identify exogenous and endogenous elements that may facilitate or hinder the diffusion process.

The aim of this dissertation is to shed light on specific parts of the diffusion process, particularly emphasising: i) the individual-level factors related to achieving various outcomes from university-industry interaction (Appendix 1); ii) the importance of understanding the unique characteristics of the transferred technologies (Appendix 2); iii) the connection between the future growth expectations of smaller technology-dedicated companies and their technology portfolios (Appendix 3); and iv) the potential diffusion channels that exist between smaller technology-dedicated companies and larger industrialist companies (Appendix 4).

The context for the empirical analysis in the dissertation is the Finnish nano- and biotechnology communities consisting of academic researchers, smaller technology-orientated companies and larger established companies. These two modern science-based technologies build mostly on discoveries originally made in academically oriented basic research. To provide more insight into the context of this dissertation, it is worthwhile to provide a brief description of these technologies.

Biotechnology relates to technological applications that use biological systems, living organisms, or derivatives thereof to make or modify products or processes for specific use. Biotechnology emerged as its own distinct field in the 1970s and has now become a very relevant source of new products and processes, particularly in the pharmaceutical industry, which was one of the first adaptor industries. The expectations regarding biotechnology have diminished somewhat in recent years; it has been claimed that major breakthroughs are mainly related to the development of new pharmaceuticals (Hopkins et al., 2007). However, there is some evidence that the uses of biotechnology are broadening into other application areas (NSF, 2008).

Nanotechnology emerged in the 1980s and, as compared to biotechnology, is in an early and more uncertain phase of its technological evolution. The field of nanotechnology centres on the control of matter on an atomic and molecular scale (structures of 100 nanometres or smaller in size); nanotechnology involves developing materials or devices on that scale. This is a multidisciplinary field encompassing both organic and inorganic research areas, and by definition, it covers a wider set of sciences and technologies than biotechnology. The potential impact of this field is still unclear, but it is estimated that the future market for nanotechnology-based products and processes will be very significant due to its diverse application areas in a variety of industries (Huang et al., 2004; Bhat, 2005; Hullman, 2006; Bozeman et al., 2007; Nikulainen, 2010; Miyazaki and Islam, 2007; Youtie et al., 2008).

The definitions of nanotechnology and biotechnology are overlapping in many cases (Rafols and Meyer, 2007; Grodal and Thoma, 2009). There is crosspollination between the two because biotechnology, by definition, focuses more on organic matter, potentially on the scale related to nanotechnology. Nanotechnology includes both organic and inorganic matter and is thus a broader research area. For example, the Finnish nano-community includes a notable share of researchers involved in biotechnology-related research (Palmberg et al., 2007; Nikulainen and Palmberg, 2010).

The empirical findings of this dissertation provide evidence that i) the outcomes of university-industry interaction are often too narrowly defined (Appendix 1), ii) boundary-spanning in research collaboration networks is related to achieving these outcomes (Appendix 1), iii) science-based technologies differ from one another in various dimensions of technology transfer (Appendix 2), iv) the expected growth of science-based companies relates to the economic value of their patent portfolio (Appendix 3), and v) there are several potential diffusion paths for science-based technologies to both traditional and high-tech industries (Appendix 4).

The remainder of this introduction is structured as follows. Section 2 discusses the research questions put forth in each of the dissertation papers. Section 3 introduces the key results of the individual papers and positions the papers in relation to the extant research by indicating their contributions to the existing body of knowledge. Section 4 addresses the implications for research, public policy and practice. Section 5 discusses the limitations of this dissertation. Finally, in Section 6, conclusions are drawn, and outlines for future research are presented.

2 Research questions

The objective in all four papers is to introduce new perspectives into the existing body of literature on the diffusion of science-based technologies. For this purpose, in the following subsections, the research questions for each of the papers are presented and discussed. All of the papers draw on related but somewhat different streams of literature, and thus, it is worthwhile to provide some brief theoretical and empirical background material for each of the topics.

The first two papers focus on the university researcher perspective and the latter two papers on the company perspective. All of them provide empirical findings. The first three papers provide statistical evidence, and the last paper (Appendix 4) makes a contribution to the literature by exploring potential diffusion paths through descriptive analysis.

Research question 1: What is the connection between the outcomes of university-industry interaction and the research collaboration networks from the perspective of an individual researcher?

The first research question is motivated by the lack of empirical evidence of the intangible outcomes of university-industry interaction and specifically of the role of research collaboration networks in achieving different types of outcomes. In particular, the latter aspect has been largely ignored in the existing literature. This is interesting because in other streams of literature, collaboration and the ability to bridge different parts of networks have been associated with higher-level performance and greater creativity (Burt, 1992; 1997; 2004; Seidel et al. 2000; Mehra et al. 2001; Cross and Cummings, 2004).

The contribution of this paper is twofold. First, it broadens the discussion of the outcomes of university-industry interaction to include intangible outcomes that have been often left outside the scope of the extant literature. The existing research on individual researcher perspectives has focused on understanding academic patenting, invention disclosures to university technology transfer offices, licensing revenues, and academic entrepreneurship (for reviews, see Bozeman, 2000; Rothaermel et al., 2007; Siegel, 2007) and has largely neglected the actual outcomes achieved using technology transfer (notable exceptions include Schartinger 2001; Palmberg 2008). In fact, the most commonly used indicators for tangible outcomes are often independent of the actions of companies. Hence, their ability to measure the actual technology transfer-related activities is somewhat limited. In this first dissertation paper, unique survey data are used to analyse the different types of outcomes in greater detail while taking into account the factors that have been associated with individual-level activities related to technology transfer.

The second contribution of this paper relates to the literature on social networks, which argues and empirically proves that the ability to combine different parts of a network (for example, in inter-organisational communication networks) is connected to higher performance and creativity on the individual level (Rosenkopf and Nerkar, 2001; Burt, 2004; Cross and Cummings, 2004). The motivation for combining these two different streams of literature stems from the argument that combining different scientific disciplines and research areas produces more industry-relevant knowledge (Gibbons et al. 1994; Foray and Gibbons, 1996; Mowery and Sampat 2005). In this paper, these arguments are taken into account when discussing the outcomes of university-industry interaction.

Research question 2: Do the specificities of transferred technology matter in technology transfer?

The second paper of this dissertation focuses on the specificities emerging from the nature of the transferred technology. The technology transfer process can be divided into several different elements (Bozeman, 2000) that all affect the outcomes of the process. In this paper, the focus is on the specificities of nanotechnology emerging from its potentially radical and disruptive nature (Darby and Zucker, 2003; Ratner and Ratner, 2003; Palmberg and Nikulainen, 2006; Bonaccorsi and Thoma, 2007; Meyer, 2007; Loveridge et al., 2008). Looking at the different elements of technology transfer, this paper identifies unique characteristics that nanotechnology brings forth, particularly as compared to other science-based technologies such as biotechnology. This question is motivated by the discussion of the radical nature of nanotechnology and whether this radical nature is related to unique characteristics that should be taken into account, particularly in public policy efforts promoting technology transfer from universities to industry.

Research question 3: Is the economic value of the technological portfolio of a technology-dedicated company related to its growth expectations?

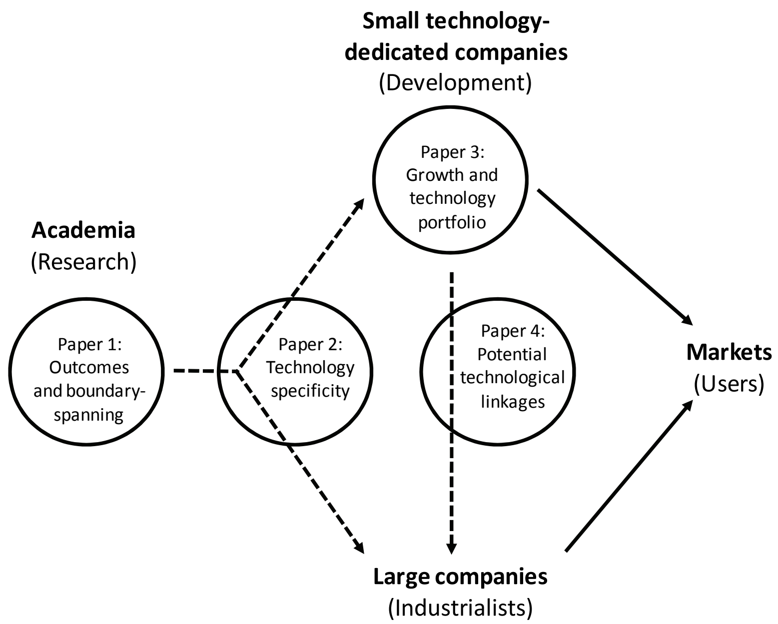
In the process of technology diffusion and technology transfer, the role of smaller technology-dedicated companies is crucial, particularly where new radical innovations are concerned (Tushman and Anderson 1986; Teece, 2006). These technology-dedicated companies often possess competences used to further develop the underlying academic knowledge—for example, the knowledge required for prototypes. From the perspective of attracting external financing, which is a significant factor in facilitating the growth of a technology-dedicated company, one of the key questions relates to the economic value of technologies and the connection between the economic value and the growth expectations of the company. To assess the economic value of a company's technologies, the third paper of this dissertation links the discussion of company growth expectations to the literature on the economic value of patents and patent portfolios (Griliches, 1990; Trajtenberg, 1990; Trajtenberg et al., 1997; Albert et al., 1991; Harhoff et al., 1999 and 2003; Reitzig, 2004; Hall et al., 2005; Nikulainen et al., 2005; Giuri and Mariani, 2005; Gambardella et al., 2006). The goal of this paper is to explore the connection between the growth expectations of a company and the economic value of its technological portfolio. If such a connection exists, the company can signal through its patenting activity that it is building its growth expectations based on the technological knowledge within the company (Myers and Majluf, 1984). This signalling may be crucial for attracting external financing and thus providing opportunities for growth and further facilitating technology diffusion.

Research question 4: Can potential diffusion channels be identified for new emerging technologies?

The fourth paper of this dissertation addresses the potential diffusion channels for science-based technologies. This exploratory study focuses on nanotechnology and identifies technological linkages between smaller technology-dedicated companies and larger established companies. This research question is motivated by the different roles that these companies have been associated with in the extant literature related to the diffusion process (Teece, 1986 and 2006; Mitchell, 1989 and 1991; Hill and Rothaermel, 2003; Rothaermel and Hill, 2005; Rothaermel and Boeker, 2008). Smaller technology-dedicated companies are potentially more equipped to develop radical and disruptive technologies because they possess the skills and knowledge related to these new technologies (Tushman and Anderson, 1986). Larger established companies are typically more attuned to adopting incremental innovations that build on existing skills and competences (Teece, 1986 and 2006). Both types of technologies, radical and incremental, can emerge from university-based research, and both can potentially be transferred to industry. Thus, understanding the different roles that different types of companies play in the diffusion of science-based technologies is an important aspect to be discussed, particularly with respect to the potential impact of science-based technologies. The broader impact of these science-based technologies can emerge through the larger established companies, which can act as industrialists for the smaller companies; the larger companies possess complementary assets, such as manufacturing competences and distribution channels, that the smaller companies often lack (Carlsson and Eliasson, 2003; Luukkonen and Palmberg, 2007). To understand the different roles of companies and the potential scale of the impact that science-based technologies may have in the future, it is worthwhile to examine the technological links between these actors to identify diffusion channels for new, potentially radical, science-based technologies such as nanotechnology.

The aim of this dissertation is not to address the entire technology diffusion and technology transfer process from every conceivable angle but rather to provide empirical insights regarding specific aspects that have been given less attention in the extant literature. In Figure 1, a simplified illustration of the diffusion of science-based technologies is provided; this illustration also positions the papers in this dissertation in relation to the broader phenomenon of technology diffusion.

Figure 1 The diffusion of science-based technologies and the positioning of the dissertation papers



3 KEY RESULTS AND CONTRIBUTIONS

The contributions of this dissertation to the extant research are related to the literature on the diffusion of science-based technologies. Table 1 presents a categorisation of the extant literature (the main references) with respect to the different aspects of technology diffusion. Each category is linked to the corresponding research question in the dissertation papers. The results of the papers are discussed in greater detail after the categorisation.

Table 1 The existing body of knowledge in related aspects of technology diffusion

Element of technology diffusion	Existing research	Contribution of dissertation
Outcomes of technology transfer	*Outcomes and interactions*	
	Patenting, licensing, TTO disclosures, and academic entrepreneurship *(Bozeman, 2000; Siegel, 2007; Rothaermel et al., 2007)* Interactions *(D'Este and Patel, 2007; Palmberg, 2008)* Intangible outcomes *(Schartinger, 2001; Palmberg, 2008)*	Paper 1. Inclusion of intangible outcomes as outcomes of university-industry interaction
	Social networks	
	Structural holes *(Burt, 1992)* Boundary-spanning and performance *(Burt, 2004; Cross and Cummings, 2004)*	Paper 1. Inclusion of boundary-spanning in research collaboration networks as a factor related to outcomes of university-industry interaction
Specificities of the transferred technology	*Nature of technology*	
	Different dimensions of technology transfer *(Bozeman, 2000)* Characteristics of nanotechnology *(Meyer, 2007)*	Paper 2. The specificities of transferred technologies should be considered when discussing technology transfer
Growth potential and patents	*Evaluation of patent portfolios*	
	Patent statistics *(Griliches, 1990)* Economic value of patents *(Harhoff et al., 2003; Gambardella et al., 2006)*	Paper 3. Establishing a connection between growth expectations and technological portfolios in smaller technology-dedicated companies
Diffusion channels	*Companies and complementary assets*	
	Discontinuous technologies *(Tushman and Anderson, 1986)* Complementary assets *(Teece, 1986 and 2006)* Absorptive capacity *(Cohen and Levinthal, 1989 and 1990)*	Paper 4. Introduces a methodology for identifying technological linkages between smaller technology-dedicated companies and larger established companies

3.1 Outcomes of technology transfer

The first of the studies (Appendix 1) contributes to the literature on technology transfer by discussing the role of intangible and tangible outcomes of university-industry interaction and by including boundary-spanning in research collaboration networks as a factor related to the outcomes. The latter aspect in particular has so far been absent from the extant literature.

The existing research on technology transfer from an individual-level perspective has focused mostly on tangible outcome indicators. Outcomes such as academic entrepreneurship, university-based patenting, licensing, and invention disclosures to university technology transfer offices have received the most attention (for reviews, see Bozeman, 2000; Rothaermel et al., 2007; Siegel, 2007). In addition, several individual-level factors have been linked to achieving these outcomes, such as educational background and industry experience (Agrawal and Henderson, 2002; Louis et al., 2001; Brennenraedts et al., 2006; Balconi and Laboranti, 2006; D'Este and Patel, 2007; D'Este and Perkmann, 2007; Palmberg, 2008; Perkmann and Walsh, 2009; Boardman and Ponomariov, 2009; Perkmann, 2009). Interestingly, some of these indicators (patenting and invention disclosures) can be seen as outcomes that potentially require only limited involvement from industry. They could be seen as 'technology push' from universities towards industry rather than as a result of university-industry interaction. It could be argued that this is a significant limitation when one is discussing the outcomes of university-industry interaction. For this reason, all types of outcomes, both tangible and intangible, should be included in the discussion. In the first paper (Appendix 1), this aspect is addressed by analysing the factors related to the following outcomes: identification of new research ideas, recognising commercial opportunities, receiving industry funding, and patenting.

The second contribution of the first paper (Appendix 1) relates to the role of research collaboration networks and, in particular, the connection between a boundary-spanning position within a network and the different types of outcomes of university-industry interaction. Individuals with a boundary-spanning position in a network are able to link different parts of the network together. This type of position is connected to higher performance and creativity on the individual level (Burt, 1992 and 2004; Seidel et al. 2000; Mehra et al. 2001; Cross and Cummings, 2004). The reason for this higher-level performance is the ability to control and take advantage of knowledge flows that relate to an individual researcher's central position in a network. Therefore, it is worthwhile to identify whether a central – or, more accurately, boundary-spanning – position in research collaboration networks is related to higher performance in technology transfer manifesting as higher levels of achieved outcomes in university-industry interaction. The inclusion of the boundary-spanning aspect combines the literature on social networks with the discussion of the increasing significance of "Mode 2"-type interdisciplinary academic research in creating industry-relevant knowledge as suggested in the literature (Gibbons et al., 1994; Foray and Gibbons, 1996; Mowery and Sampat, 2004).

The empirical analysis is based on three datasets. The data on technology transfer from an individual perspective come from a survey directed at Finnish university researchers active in the field of nanotechnology. This survey focused particularly on the motivations, modes of interaction and outcomes related to technology transfer and collected information on educational and professional backgrounds. The research collaboration networks were created based on patent and publication data, where co-inventorship and co-authorship were used to connect individual academic researchers.

The empirical results indicate that the intangible outcomes (identification of new research questions and commercial opportunities) are as common as the tangible outcomes (receiving funding and patenting). Interestingly, the individual factors related to the different outcomes were quite similar, with only some variation between the outcomes. Particularly interesting are the results regarding the boundary-spanning position in the publication network; this position was positively connected to all but one of the outcomes, suggesting that the ability to connect different parts of the basic research-orientated publication network does relate to higher levels of outcomes. A boundary-spanning position in an applied-orientated patent network proved to be an insignificant factor for all outcomes except for receiving industry funding. These findings provide a novel contribution to the extant research. While earlier research has linked a boundary-spanning role in social networks to various performance indicators (for example, Cross and Cummings, 2004), the connection between boundary-spanning in research collaboration networks and technology transfer has received limited attention.

While the role of boundary-spanning in research collaboration in achieving both intangible and tangible outcomes is the main contribution of the paper, there are some relevant findings related to other outcome-associated factors that provide an additional contribution to the extant literature. The results indicate that the most significant factors related to the outcomes were educational and professional background, academic productivity (number of publications), basic research-related challenges and problems related to ownership issues, and, in particular, commercial motivations on the part of academic researchers. These results also provide a novel contribution to the literature by extending the discussion to include identifying factors related to a broader set of outcomes than has been addressed in prior research.

3.2 Specificities of the transferred technology

The second paper of this dissertation (Appendix 2) contributes to the extant literature by focusing on the specificities of technology transfer emerging from the nature of the technology in question. Technology transfer has been addressed in prior research mostly without taking the technological context into account. While research has focused on different types of knowledge (tacit and explicit) and technologies (product and process), it has rarely analysed technology transfer in a specific technological context to identify specificities related to the technology in question. To answer the research question of whether the specificities of transferred technology matter in technology transfer, the second paper highlights the specificities of nanotechnology as compared to other science-based technologies such as biotechnology.

Nanotechnology has become a topic of increasing interest among social science scholars (Darby and Zucker, 2003; Heinze, 2004; Palmberg and Nikulainen, 2006; Meyer, 2007; Lipsey et al., 2005; Youtie et al., 2008), most of whom contribute to the conversation through conceptual discussions or a focus on identifying publication and patenting trends (Heinze, 2004; Palmberg and Nikulainen, 2006; OECD, 2009). In addition, some efforts have been made to identify application areas for this new science-based technology (Hullmann, 2006). What has not been addressed is, for example, whether nanotechnology introduces unique challenges or modes of interaction related to technology transfer. This is an important issue because most of the research and development related to nanotechnology is currently conducted in academia (Miyazaki and Islam, 2007). To facilitate the diffusion of academic findings, it is necessary to understand the unique characteristics of nanotechnology.

The second paper of this dissertation (Appendix 2) uses survey data collected from the Finnish nanotechnology-related community focusing on university researchers (also used in Appendix 1). These data focus on the individual aspects of technology transfer, such as motivations and challenges in technology transfer. In this empirical analysis, these different factors of technology transfer are connected to the intensity with which the individual researchers are engaged in nanotechnology-related research.

The results of the analysis indicate that the transfer of nanotechnology differs from the transfer of other science-based technologies only in a few dimensions. Based on the statistical evidence, it seems that researchers more involved in nanotechnology-related research are more motivated by the availability of new research instrumentation and commercial opportunities than are researchers working in other research areas. Nanotechnology-orientated researchers are also more likely to interact with companies through joint publications and joint facilities. In addition, nanotechnology-orientated researchers' view is that they are less passive in technology transfer than are researchers in other areas. Nanotechnology-orientated researchers also view their basic research orientation as a more significant challenge than do researchers in other research areas. Finally, the results confirm that nanotechnology is more related to physics and chemistry than to the bio/medical sciences, as suggested in the extant literature (Schummer, 2004; Meyer, 2007). Together, these findings illustrate that the context of technology transfer and the actual object being transferred do make a difference.

3.3 Growth potential and patents

Smaller technology-dedicated companies often play an important role in the diffusion of science-based technologies. Based on their technological expertise, these companies develop scientific discoveries that will lead towards the development of viable products and processes through testing and prototyping. The outcomes of these activities can be commercialised by the company itself or sold/licensed to larger companies with potentially more refined commercialisation competences (Teece, 1986 and 2006; Carlsson and Eliasson, 2003). Thus, the role of smaller technology-dedicated companies is evidently crucial, but they face a significant challenge in securing financing for the development activities prior to the commercialisation activities. For this reason, the research question in the third paper of this dissertation (Appendix 3) focuses on the relationship between the economic value of the technological portfolio of a smaller technology-dedicated company and the company's growth expectations. If the economic value of the technological portfolio of a smaller technology-dedicated company is related to the company's potential future growth, it may prove to be a significant signalling mechanism for external financiers.

The extant literature on the economic value of the technological portfolios of companies has focused on patenting statistics using a variety of different indicators: for example, patent citations (Trajtenberg, 1990; Trajtenberg et al., 1997; Harhoff et al., 1999 and 2003; Reitzig, 2004; Hall et al., 2005; Nikulainen et al., 2005; Giuri and Mariani, 2005; Gambardella et al., 2006). While these patent statistics have some well-known limitations, they are one of the few indicators of innovative output for companies (Griliches, 1990; Kleinknecht et al., 2002; Nikulainen et al., 2005). In recent decades, there has been a significant expansion of the literature on patents, where patent statistics have been linked to company performance among other aspects (for example, Albert et al., 1991; Hall et al. 2005). In the third paper of this dissertation (Appendix 3), we see indications that the economic value of the technological portfolio of the smaller technology-dedicated companies may be related to the companies' future growth expectations because the companies rely on their technological competences to succeed in growing. For this reason, it is worthwhile to identify whether there is such a connection for science-based companies. If this connection exists, signalling it may be useful in reducing asymmetric information between external financiers and technology-dedicated companies (Myers and Majluf, 1984). This may potentially lead to arrangements that secure additional funding for technology-dedicated companies.

The empirical analysis in the third paper of this dissertation (Appendix 3) focuses on biotechnology companies in Finland. The analysis is based on two surveys directed towards Finnish biotechnology companies and patent data that provide information on the technological portfolio of the companies. The results indicate that the future growth expectations of the companies are statistically and positively related to the number of backward citations of their patent portfolio. Patent citations are reported in patent publications to indicate the prior art (i.e., existing patents) upon which the patent builds. These backward citations are thus citations of earlier patents. The existing empirical research on patent statistics and particularly on patent citations has also linked backward citations to the economic value of a patent (Harhoff et al., 1999 and 2003; Gambardella et al., 2006), although other indicators have been found to be more reliable. This aspect is addressed in greater detail in the discussion of the limitations of this dissertation. The results of the empirical analysis indicate that the Finnish biotechnology companies can signal the economic value of their patent portfolio in an objective manner that may be useful for external financiers as an additional indicator of the future value of the company.

3.4 Diffusion channels

In the diffusion of science-based technologies, different types of companies play diverse roles depending on the nature of the technology in question and on the competences possessed by the actors. Smaller technology-dedicated companies have an advantage with more radical technologies based on their knowledge base in these technologies, whereas with incremental technologies, larger and more established companies may have the advantage because they may already have an existing competence base related to these technologies (Tushman and Anderson, 1986; Teece, 1986 and 2006). Based on the argumentation in the extant literature, the research question in the fourth paper of this dissertation (Appendix 4) relates to potential diffusion channels in Finland that may exist between the smaller and larger companies in the context of nanotechnology.

The extant literature on the roles of different types of companies in technology diffusion has focused on identifying differences between incremental innovations and radical, discontinuous innovations (Tushman and Anderson, 1986) and differences between complementary assets (Teece, 1986 and 2006) and absorptive capacity (Cohen and Levinthal, 1989 and 1990). While these contributions provide a picture of the different roles involved, in particular with emerging science-based technologies, empirical evidence in specific technological contexts is often lacking. This gap highlights the need to understand the potential role and diffusion of nanotechnology in more detail to provide a better understanding of the potential future impact of this science-based technology.

This paper uses patent and company data to identify the potential diffusion channels of nanotechnology in Finland. It first compares the patenting activities in nanotechnology and, as a comparison group, biotechnology with respect to the overall patenting profile of Finland. The empirical analysis then focuses on the patenting activities of nanotechnology-dedicated companies. In this descriptive analysis, the aim is to identify similarities in patenting activities between the nanotechnology-dedicated companies and the larger, established companies in Finland. Finally, the absorptive capacity of the larger companies with links to nanotechnology is addressed using quantitative proxies.

The results of the empirical analysis indicate that the patenting activities in nanotechnology match the patenting activities of Finland to a greater degree than do the patenting activities of biotechnology. This finding suggests that nanotechnology may potentially have more of an impact than biotechnology on the overall innovation activities in Finland. When looking at the more detailed findings on technological links based on similarities in patenting activity, we can see that nanotechnology is potentially linked to various industries. This suggests that nanotechnology has the potential to become a general-purpose technology that will be used in various industries in different ways, as suggested in the extant literature (Palmberg et al., 2007; Youtie et al., 2008). Finally, the results indicate that the larger companies with potential links to nanotechnology have higher R&D intensity than other larger companies with no links to nanotechnology. R&D intensity has been used in the literature to approximate absorptive capacity (Cohen and Levinthal, 1989), and thus, the empirical findings suggest that nanotechnology is linked to companies with higher-than-average absorptive capacity. This may facilitate the diffusion of nanotechnological innovations.

The contribution of the fourth paper of this dissertation (Appendix 4) to the extant literature builds on the vast theoretical and conceptual literature on this topic (for example Tushman and Anderson, 1986; Teece, 1986 and 2006; Cohen and Levinthal, 1990). The paper makes a methodological and empirical contribution to the discussion of emerging science-based technologies in this context. Whereas most of the literature on nanotechnology has focused on patent and publications statistics, only a few studies have tried to identify application areas for nanotechnology (Hullmann, 2006). The empirical results of the fourth paper highlight the potentially wide-ranging applicability of nanotechnology in both traditional and high-tech industries.

The different papers of this dissertation use different types of research design, data and levels of analysis; Table 2 summarises these aspects and highlights the main contributions of the papers.

Table 2 Summary of the research questions, research design, key results, and contributions of the papers

	Paper 1	Paper 2	Paper 3	Paper 4
Title	The outcomes of individual-level technology transfer and the role of research collaboration networks	Transferring science-based technologies - Does nanotechnology make a difference?	Patent citations indicating present value of the biotechnology business	Identifying nanotechnological linkages in the Finnish economy - An explorative study
Key question	What are the outcomes of university-industry interaction and what factors relate to them?	Should the object of technology transfer be given more consideration?	How can the economic value of a technology portfolio of a technology-dedicated company be signaled to external financiers?	How can potential diffusion paths be identified for new science-based technologies?
Specific research question	What is the role of boundary-spanning in research collaboration networks in achieving outcomes from university-industry interaction?	How do the unique characteristics of nanotechnology reflect on different elements of technology transfer?	What is the connection between future growth expectations of technology-dedicated companies and their technology portfolio?	Can potential diffusion paths be identified based on similarities in patenting activity?
Level of analysis	Individual university researchers	Individual university researchers	Companies	Companies
Research design	Empirical, quantitative, cross-sectional, statistical	Empirical, quantitative, cross-sectional, statistical	Empirical, quantitative, statistical	Empirical, quantitative, cross-sectional, descriptive
Data source	ETLA Nanotechnology survey* Patent data (Questel) Publication data (ISI SCI-Index)	ETLA Nanotechnology survey*	ETLA Biotechnology survey 2002** ETLA Biotechnology survey 2004*** Patent data (Delphion online & ETLA's FEPOCI patent database)	Asiakastieto company registry TE500 company database Patent data (Delphion online)
Key results and insights	1. Intangible outcomes of university-industry interaction should be given more attention. 2. Boundary-spanning has a positive connection with various types of outcomes. 3. Promotion of interdisciplinary research may result in more industry relevant outcomes.	1. Characteristics of the transferred technology should be taken into account when discussing university-industry interaction. 2. Nanotechnology differs from other technologies in only a few dimensions of technology transfer.	1. Expected future growth is positively related patent citations (backward citations). 2. Patent statistics can be used by external financier as a signal of the economic value of the company's patent portfolio.	1. Nanotechnology exhibits signs of being widely applicable. 2. Nanotechnology has potential links to various different industries. 3. Larger companies with potential links to nanotechnology may have high absorptive capacity facilitating technology diffusion.

*For more details of the survey, its design, questionnaires and basic tabulations, see Palmberg, Pajarinen and Nikulainen (2007).
** For more details of the survey, see Hermans and Luukkonen (2002).
*** For more details of the survey, see Hermans et al. (2005).

4 Implications for research, public policy and practice

4.1 Implications for research

This dissertation explores specific aspects of the diffusion of science-based technologies. The dissertation papers identify areas in the extant literature where significant gaps exist and make related empirical contributions. Because the papers focus on specific stages of this process, overarching, broad implications regarding the theory of technology diffusion are hard to establish. Therefore, it is more productive to focus on the aspects addressed in the dissertation papers.

The first paper (Appendix 1) indicates that in discussing the outcomes of university-industry interaction, the prevailing focus in the extant literature on patenting and licensing takes into account only a small fraction of the possible outcomes. It is understandable that the extant literature has focused heavily on patent and licensing data because they are more readily available than other types of data, particularly data on intangible outcomes. The problem with using the patent and licensing indicators is their narrow focus. University-industry interaction clearly relates to a much wider set of outcomes that may not be directly applicable in industry but may eventually lead to outcomes that are applied there. Taking into consideration a broader range of outcomes may lead to a better understanding of the potentially beneficial interaction cycle between universities and companies.

The second finding in the first paper (Appendix 1) – that boundary-spanning in research collaboration networks is related to achieving more outcomes from industry interaction – indicates that the ability to combine different research areas relates to the discussion of technology transfer as suggested in the literature on the "Mode 2"-type of research. This highlights the role of interdisciplinary research as an important source of industry-relevant knowledge. Interdisciplinary research has attracted attention in the extant literature, with attempts made to define its nature and indicate where it most commonly occurs. Interestingly, only limited interest has emerged regarding its connection with the creation of industry-relevant knowledge.

Most of the existing literature on technology transfer treats technologies as one entity and makes the distinction between different technologies based only on the educational background and/or the current affiliation of a researcher. This approach is somewhat limiting; the second paper of this dissertation (Appendix

2) shows that technologies differ in some dimensions of technology transfer. Therefore, in future research on technology transfer, more consideration should be given to the transferred object, whether it is tacit knowledge or a tangible artefact. The incorporation of this aspect should lend new insights to the discussion of the role of different types of transfer objects in different phases of technology evolution. Emerging technologies may face challenges related to a basic research orientation, whereas more established and applied technologies may have very unique challenges that are quite different from those of emerging technologies.

The findings in the third paper (Appendix 3) extend the conclusions of the existing literature regarding the use of patent statistics and the connection between the growth expectations of technology-dedicated companies and the value of their technological portfolio. In establishing this connection, we find that the uses of patent statistics are broader than suggested in the existing research. Particularly interesting is the potential use of patent statistics by external financiers in their decision-making process. Identifying the role of patent statistics in assessing the value of the company's technological portfolio when making financing decisions could be an interesting future research avenue.

The fourth paper (Appendix 4) explores the potential diffusion channels for nanotechnology in Finland. Based on empirical analysis, the paper makes an attempt to identify and understand the diffusion paths of nanotechnology. The existing research often relies on historical data to discuss the impact of specific technologies. This methodological choice has broadened our understanding of these technologies, but only from a historical perspective. To understand the current (and to predict the future) impact of a specific emerging technology, different methods need to be employed. These analyses will require data that is more descriptive and often qualitative, which means that statistical methods will be difficult to use. For this reason, a wide set of methodological approaches should be employed in discussing the potential future impact of emerging science-based technologies such as nanotechnology.

4.2 Implications for public policy

The diffusion processes of science-based technologies are complex and therefore direct policy implications are challenging to draw. However, the findings in the dissertation papers have some potential implications for public policy. One of the implications of the first paper (Appendix 1) relates to the indicators based on which the outcomes of university-industry interaction are measured.

While patents by university researchers, licensing revenues and invention disclosures to university technology transfer offices are readily available indicators of potentially industry-relevant innovative activities, they fall short of actually measuring the diversity of potential outcomes from this interaction. The tangible nature of patents, licensing revenues and invention disclosures makes the use of these indicators appealing for social sciences scholars as well, as is evident from the extant literature (Siegel 2007; Rothaermel et al. 2007). For this reason, the intangible outcomes have received surprisingly limited attention among both scholars and policymakers in government bodies and university administration. The results of the first paper suggest that the inclusion of intangible measures of outcomes could be an additional dimension when one discusses the outcomes of university-industry interaction. In fact, it should be noted that some of the currently measured tangible outcomes (i.e., patent and invention disclosures) potentially require no industry involvement and are more properly 'technology push' outcomes that may or may not be interesting from the industry perspective.

The other implication of the first paper (Appendix 1) is the role of boundary-spanning and interdisciplinary research in achieving more industry-relevant research results. In the extant literature, it is argued that interdisciplinary academic research is becoming increasingly important in creating industry-relevant knowledge (Gibbons et al., 1994; Foray and Gibbons, 1996; Mowery and Sampat, 2004). The findings in the first paper, on the positive connection between boundary-spanning (i.e., the ability to connect different parts of the research collaboration networks) and different types of outcomes, suggests that interdisciplinary research has a connection – albeit a fairly small one – to achieving outcomes from university-industry interaction. This result highlights the importance of promoting interdisciplinary research. This item has been on the agenda of policy-makers in the past, particularly during recent decades, but most recently, the promotion of this type of research may have received less attention than it did previously (for an example of this, see the results of The Evaluation of the Finnish National Innovation System, www.evaluation.fi).

The policy implications derived from the second paper of the dissertation (Appendix 2) relate to the promotion and facilitation of technology transfer. A fairly common approach in public policy with respect to technology transfer is to treat all technologies equally. In many cases, this may be a valid approach, but if the policy-makers are interested in promoting a specific area of technology (for example, nanotechnology), it may be worthwhile to take into account the unique technology-specific factors that relate to the diffusion of the technology in question.

The third paper (Appendix 3) is more focused on technology-dedicated companies and their activities, and thus, direct public policy implications are somewhat challenging to develop. If a public actor acts as an investor, the findings of the third paper may prove useful (for example, in Finland, Sitra). Public actors may have an additional evaluation criterion to use to determine the potential economic value of the technology portfolio of the potential investee company. This may prove useful if a public investor has limited (asymmetric) information regarding the technological competences of the potential investee company.

The public policy implications of the fourth paper of the dissertation (Appendix 4) relate to the facilitation of the technology diffusion of science-based technologies. For policy-makers, it is worthwhile to understand the potential impact of a new technology fairly soon after the initial emergence of the technology. Particularly relevant is the information on potential application industries. For example, in Finland, large public investments were made in the biotechnology sector in the 1990s and 2000s, but because Finland is not very specialised in pharmaceuticals, most of the eventual proceeds generated by these investments were in fact made by foreign pharmaceutical companies. Of course, the development of new pharmaceuticals serves the broader goals of the healthcare sector, but ultimately, public investors may not have imagined that most financial gains and increases in employment would not materialise domestically. Though biotechnology did not have strong connections with the established industries in Finland, the results of the fourth paper show a wide range of potential diffusion channels for nanotechnology. The companies with potential technological links represent a wide set of industries both from more traditional sectors, such as paper and machinery, and from newer sectors, such as telecommunications. For policy-makers, these findings highlight the general-purpose nature of nanotechnology, and the promotion of this field may yield significant results in the long term for both established and emerging industrial sectors. In addition, companies with potential links to nanotechnology have, based on this approximation, higher-than-average absorptive capacity, and this should facilitate the diffusion process.

4.3 Implications for practice

The majority of the implications of the dissertation papers relate to public policy, but some implications based on the findings could also be useful for practitioners in academia and in companies. The findings of the first paper (Appendix 1) suggest that individuals with boundary-spanning positions are more likely to achieve higher levels of outcomes than their less connected peers when interacting with companies. Thus, if an individual university researcher is interested in achieving more outcomes from industry interaction; one potential method that he or she can use to achieve this goal is to interact with researchers outside his or her own range of familiar partners, potentially crossing traditional academic discipline boundaries.

The findings in the third and fourth papers of this dissertation provide some implications that may be useful for technology-dedicated companies. The results of the third paper (Appendix 3) suggest that a patent portfolio and its estimated value could be used to signal quality to external parties, particularly external financiers. External financiers may already have significant knowledge of the technological developments related to the company in question, but they may also be interested in objective estimations of the value of the technologies developed within the investee companies. This is particularly true for public financiers, who often have a more limited perspective on the technological developments related to the investee's growth potential.

The empirical results of the fourth paper (Appendix 4) highlight the identification of potential diffusion channels. Smaller science-based companies sometimes have difficulty identifying potential application areas or industries for their innovations. For this reason, the analysis of similarities in patenting activities may prove to be a useful tool in identifying larger companies with technological activities in the same technological areas. This also works the other way around; larger companies can actively screen their technological landscape to identify smaller companies that may possess the necessary skills to master radical innovations, which the larger companies can then develop further towards commercialisation.

5 LIMITATIONS

The most significant limitation of this dissertation relates to the broad phenomenon under investigation. Technology diffusion includes various stages and elements that provide a multitude of different potential analytical perspectives. Because the discussion in this dissertation is focused on emerging science-based technologies, the emphasis is more on the early stages of the diffusion process. This allows one to highlight the challenges in the very early stages of the process after the creation of the knowledge upon which the science-based technologies build.

Even with a focus on the early stages of diffusion, the contributions of this dissertation need to be positioned in relation to the vast amount of literature on this topic. For this reason, the papers in this dissertation are snapshots of different parts of early-stage diffusion, contributing to the extant literature in places where clear contributions can be made. To some degree, this can be seen as a major limitation. However, due to the broad scale of the phenomenon at hand, the necessary limiting choice allowed for proper analysis of specific research questions.

The second general limitation of the dissertation is its focus on the diffusion of science-based technologies in Finland. This poses some challenges to the generalisation of the research findings. While this is an aspect that should be kept in mind when interpreting the findings, it should also be noted that Finland represents a small open economy that relies heavily on knowledge creation as a source of industrial renewal. Its scientific community and industry activity can be argued to be similar to that in many other countries, particularly European ones. The industrial structure of Finland does have some unique characteristics related to the dominance of the telecommunication, pulp and paper, and machinery industries, but it can be argued that overall differences from other countries in terms of knowledge creation and technology diffusion are fairly small. If the aim were to improve the generalisation of the empirical results of this dissertation, similar data or analyses from other countries would provide more insight into the research questions proposed in the dissertation papers.

Additionally, there are some more specific limitations related to the individual papers. The first paper in this dissertation (Appendix 1) addresses the outcomes of university-industry interaction. The most significant limitation in the paper is the focus on the perspective of the university researcher. In an ideal situation, one would form dyadic pairs of university researchers and companies that could be used to verify the achieved outcomes. Unfortunately, this would be very challenging because university researchers interact with various companies; thus, the formation of such dyadic pairs would have been beyond the scope of this dissertation. In a related study (Palmberg 2008), this aspect has been addressed on an aggregate level, with the findings suggesting that university and company researchers do have some differences in their perceptions of the outcomes based on their interaction. This aspect could be further explored, for example, by focusing on a specific technological field, which would allow for a more in-depth analysis both from the quantitative and the qualitative perspectives.

The second limitation of the first paper (Appendix 1) relates to the construction of the research collaboration networks. Although significant effort was made in the paper to expand the network to be sufficiently large to allow a proper analysis, it still is a partial network; we included only the co-authors of the co-authors (and in the case of patent-based networks, the co-inventors of the co-inventors) and no others. To provide a more realistic picture, the entire research collaboration network should be created, but that would require an effort beyond the scope of this dissertation.

In the second paper (Appendix 2), the most significant limitation relates to the comparison group for the dependent variable. Because the dependent variable measures the intensity with which the university researcher is engaged in nanotechnology-related research, the research area for the less nanotechnology-orientated researchers remains somewhat unclear. The educational backgrounds of the less nanotechnology-orientated researchers suggest that they are most likely active in medicine- and biotechnology-related areas. Because the focus of the second paper was on nanotechnology and its differences from other research areas, this limitation does not significantly affect the interpretation of the empirical findings. In future research addressing the technological specificities of technology transfer, research areas could be given more attention; this greater attention would provide more insight into various types of technologies instead of just one.

The third paper of the dissertation (Appendix 3) has some data-related limitations. Most significantly, many of the originally surveyed companies (81 in total) did not have any patents, and this limited the size of the sample to 30 companies. This reduction in sample size is related to the fairly recent emergence of the biotechnology companies in Finland, which had led to a situation in which only a few companies have a lengthy record of innovation. A follow-up study of the biotechnology companies in Finland could provide a larger sample given that patenting activity most likely has increased since the time of the original analysis.

The second limitation of the third paper (Appendix 3) is related to the patent indicators through which the economic value of a patent is estimated. Unfortunately, only a limited set of patent indicators was available in the patent data used, leaving out some potential indicators that have been associated with the economic value of patents (such as the size of a patent family and the number of claims; for more on these factors, see Gambardella et al., 2006). In future research, the inclusion of these indicators may provide more insight into the relationship between the economic value of the technological portfolio and the expected growth of technology-dedicated companies.

The limitations of the fourth paper (Appendix 4) relate to the data and methodology. One of the most significant challenges with emerging technologies is incomplete data classification. This relates particularly to patent and company classifications. For a newly emerging science-based technology such as nanotechnology, significant time elapses between the initial emergence of the underlying inventions and the creation of useful categories in databases. Because this classification infrastructure is not currently available, in the fourth paper of this dissertation, secondary data from public sources are used to identify the Finnish companies that are active in the development of nanotechnology. While these secondary public sources can be seen as very reliable, they do not provide information regarding the intensity with which the identified companies are engaged in nanotechnology-related activities. In the future, as the classification systems develop, more information on these companies may become available, facilitating the identification process.

The other significant limitation of the fourth paper (Appendix 4) is the discussion of potential technological linkages. As stated clearly in the paper, the aim was not to provide concrete empirical evidence of existing links between the smaller technology-dedicated companies and the larger established companies. The aim was to provide an indication of potential links that may or may not exist. To identify existing links between the different types of actors, other types of data (for example, qualitative data) would be necessary. This type of data could also address the issue of absorptive capacity in greater detail instead of quantitatively approximating it.

6 Future research

This dissertation has addressed technology diffusion by focusing on specific stages of the process. It highlights areas where the extant literature has gaps and provides empirical contributions to shed more light on these aspects. The research focuses on the early stages of the diffusion process and approaches it from the individual university researcher and company perspectives.

Several potential directions for future research can be identified on the basis of the findings in this dissertation. Some of the research themes that could be further explored are as follows: i) the role of boundary-spanning in different types of interaction modes between university researchers and companies, ii) extension of the analysis of the technological specificity of technology transfer to other technologies in addition to nanotechnology, and iii) the connection between expected company growth and technological portfolios with more advanced patent indicators. Of these potential research themes, the first two appear to be the areas where the most significant contributions can be made.

The boundary-spanning position in various networks and its relation to different types of performance indicators has been addressed in the extant literature (Burt, 1992 and 2004; Seidel et al. 2000; Mehra et al. 2001; Cross and Cummings, 2004). Because most of the empirical literature on individual-level boundary-spanning relates to internal communication networks, it would be interesting to identify whether this unique role of intermediary is also relevant in other contexts beyond the outcomes of technology transfer. This ability to connect different parts of different types of networks may reflect on various performance indicators, providing more information on the potentially significant role of these key individuals. One example of a potential future research avenue would be an assessment of the role of boundary-spanning in different types of interaction modes by which university researchers engage with companies (D'Este and Perkmann, 2007; Palmberg, 2008). This would not only provide more insight into the technology transfer process but also potentially yield some relevant policy implications.

The technological specificity of technology transfer is addressed in the second paper of this dissertation (Appendix 2). As discussed in that paper, the extant literature often treats all science-based technologies as having the same characteristics affecting the transfer process. The empirical evidence provided in this dissertation shows that there are clear differences between different technologies. Taking these unique characteristics into account, many of the existing empirical findings may be revisited, thus providing more insight into the uniqueness of technology-specific technology transfer.

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