The Geography of the Knowledge Economy: Innovation, Interaction and Industrial Development.

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2012

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The Geography of the Knowledge Economy – Innovation, Interaction and Industrial Development is his PhD thesis.

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The Geography of the Knowledge Economy – Innovation, Interaction and Industrial Development

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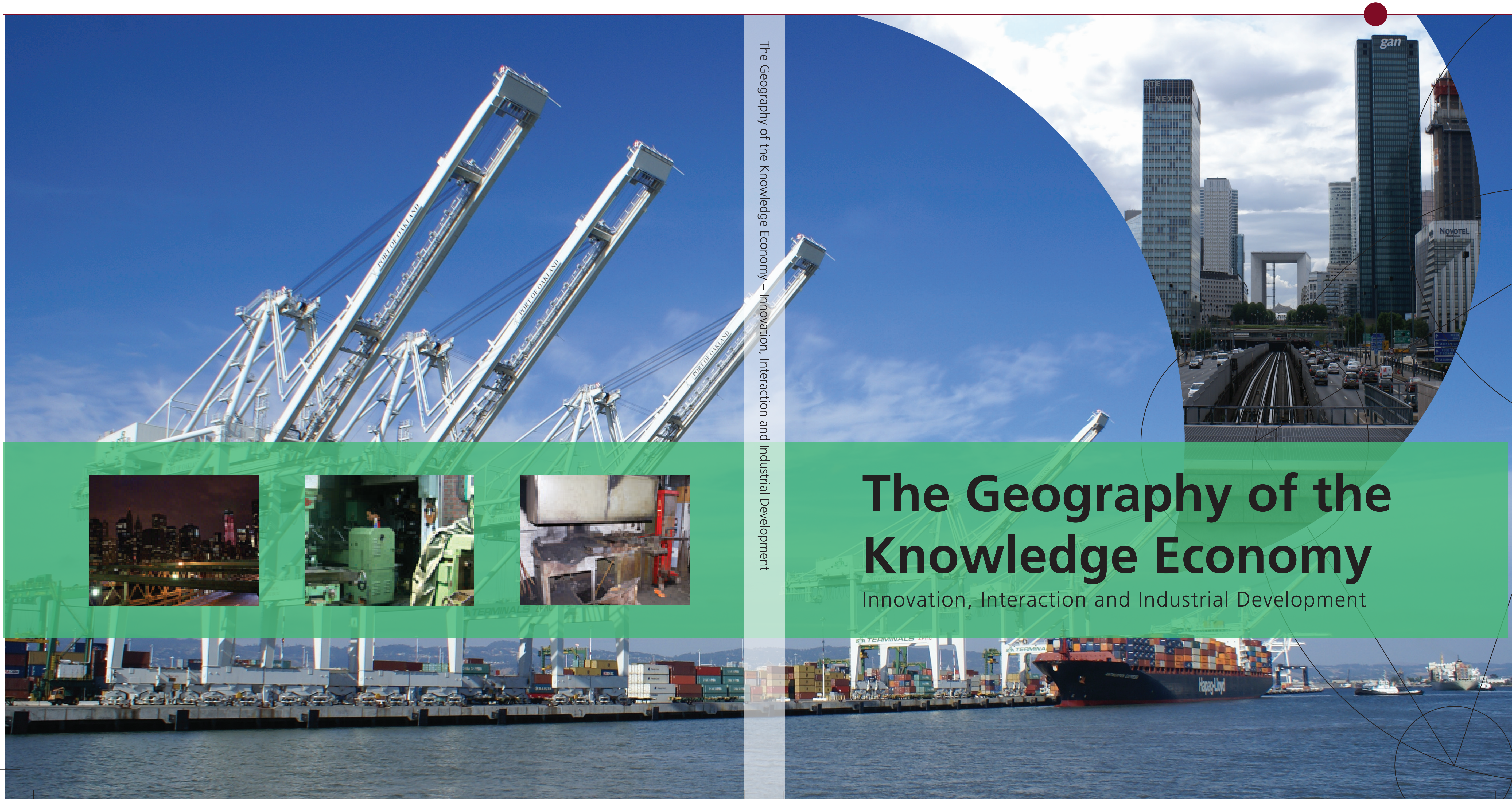

The Geography of the Knowledge Economy

Innovation, Interaction and Industrial Development

THE GEOGRAPHY OF THE KNOWLEDGE ECONOMY

The Geography of the Knowledge Economy
– Innovation, Interaction and Industrial Development

PhD thesis

Teis Hansen

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TABLE OF CONTENTS

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ABSTRACT

Today, acquisition, creation and utilisation of knowledge are the key factors explaining economic development. Firms must constantly employ new knowledge and combine different types of knowledge in their activities to maintain competitiveness. This thesis examines the knowledge economy from two perspectives. The first focuses on the role of geographical proximity for interactive knowledge creation. It follows from the increasing knowledge intensity of the economy that it is highly unlikely that firms can access knowledge of a sufficient depth and variety within their own boundaries. Papers I-III in the thesis analyse the impact of geographical proximity on such collaborative processes of knowledge creation and innovation. The second perspective is concerned with the development of low- and medium low-tech manufacturing industries in high-wage countries. While high-tech sectors are increasingly seen as vital to economic development, low- and medium low-tech industries maintain economic importance in high-wage countries. Papers IV-VI in the thesis examine the responses of low- and medium low-tech manufacturing industries to the challenges of the knowledge economy.

The results of the first part of the thesis highlight that geographical proximity has a significant impact on interactive knowledge creation; however, the effect of geography cannot be isolated from other forms of proximity, such as established social relationships and common institutional frameworks. In fact, it is exactly by leaving behind the narrow focus on geography, and replacing it with an approach sensitive to social, institutional, cognitive and organisational relations, that the importance of geography for interactive knowledge creation becomes evident. While the role of geographical proximity varies depending on collaboration motives, it is particularly important in collaboration projects at the core of innovation processes, where the objective is to access technologies, obtain knowledge or reduce the innovation time-span.

The main conclusion of the thesis' second part is that low- and medium low-tech industries maintain significant economic importance in high-wage countries, contrary to the assumptions of much academic and policy work. However, the character and activities of these industries are profoundly changing. The papers highlight that they are not passively waiting to be outcompeted by firms from low-cost countries. Instead, they are actively pursuing strategies to maintain competitiveness and increase the value added of products and processes. These findings underline the importance of a broad conception of the knowledge economy, which goes beyond research intensive industries.

Keywords

Knowledge economy, innovation, knowledge linkages, proximity, collaboration, low- and medium low-tech manufacturing, Denmark

DANSK SAMMENFATNING

Tilegnelse, skabelse og udnyttelse af viden er i dag de centrale faktorer for økonomisk udvikling. Virksomheder må konstant anvende ny viden og kombinere forskellige former for viden for at forblive konkurrencedygtige. Denne afhandling undersøger videnøkonomien fra to perspektiver. Det første fokuserer på betydningen af geografisk nærhed for interaktiv skabelse af viden. Som en konsekvens af økonomiens øgede videnintensitet er det højest usandsynligt, at virksomheder har adgang til viden af en tilstrækkelig brede og dybde indenfor egne rammer. Artiklerne I-II i afhandlingen analyserer effekten af geografisk nærhed på sådanne samarbejdsprocesser omkring skabelse af viden og innovation. Det andet perspektiv omhandler udviklingen af lav- og medium lavteknologiske fremstillingsindustrier i højtlønslande. Selvom højteknologiske sektorer i stigende grad bliver betragtet som vitale for økonomisk udvikling, er lav- og medium lavteknologiske industrier fortsat af stor økonomisk betydning i højtlønslande. Artiklerne IV-VI i afhandlingen undersøger lav- og medium lavteknologiske fremstillingsindustriers reaktion på videnøkonomiens udfordringer.

Resultaterne af afhandlingens første del viser, at geografisk nærhed har en betydelig indflydelse på interaktiv skabelse af viden; geografiens indflydelse kan imidlertid ikke isoleres fra andre former for nærhed, som for eksempel etablerede sociale relationer og fælles institutionelle rammer. Faktisk er det netop ved at fravælge et snævert fokus på geografi og i stedet anvende en tilgang, der tager sociale, institutionelle, kognitive og organisatoriske relationer i betragtning, at vigtigheden af geografi for interaktiv skabelse af viden bliver tydelig. Betydningen af geografisk nærhed varierer, afhængig af samarbejdsmotiver, men geografisk nærhed er særlig vigtig i samarbejdsprojekter, hvor formålet er at få adgang til teknologi, opnå viden eller reducere tidsforbruget i udviklingsforløb, og som dermed er direkte relaterede til innovationsprocesser.

Hovedkonklusionen i afhandlingens anden del er, at lav- og medium lavteknologiske industrier fortsat er af betydelig økonomisk indflydelse i højtlønslande, i modsætning til antagelserne bag megen forskning og policyudvikling. Karakteren af disse industrier og deres aktiviteter ændrer sig imidlertid grundlæggende. Artiklerne viser, at de ikke passivt venter på at blive udkonkurreret af virksomheder fra lavtlønslande. I stedet forfølger de aktivt strategier for at fastholde konkurrenceevne og øge værdiforøgelsen i produkter og processer. Disse konklusioner understreger, at videnøkonomien består af andet og mere end forskningsintensive industrier.

Nøgleord

Videnøkonomi, innovation, interaktiv skabelse af viden, nærhed, samarbejde, lav- og medium lavteknologiske fremstillingsindustrier, Danmark

LIST OF PAPERS

The PhD thesis consists of the following six papers:

Paper I: Hansen, Teis (2012): Substitution or overlap? The relations between geographical and non-spatial proximity dimensions in collaborative innovation projects. *Submitted to a journal, August 2011. In revised version, May 2012.*

Paper II: Hansen, Teis (2012): Juggling with proximity and distance. Collaborative product development in the Danish cleantech industry. *Submitted to a journal, March 2012.*

Paper III: Hansen, Teis (2011): Cross-border innovation – regional integration in the Øresund Region 1994-2009. *Submitted to a journal, October 2011.*

Paper IV: Hansen, Teis & Winther, Lars (2011): Innovation, regional development and relations between high- and low-tech industries. *European Urban and Regional Studies*, Vol. 18 (3), Pp 321-339.

Paper V: Hansen, Teis (2010): The Danish fabricated metal industry: A competitive medium-low-tech industry in a high-wage country. *Danish Journal of Geography*, Vol. 110 (1), Pp 65-80.

Paper VI: Hansen, Ronnie F.; Hansen, Teis & Winther, Lars (2012): Human Capital in Low-Tech Manufacturing: the Geography of the Knowledge Economy in Denmark. *Submitted to a journal, April 2012.*

1. INTRODUCTION

This thesis deals with the geographical and sectoral organisation of economic activity in the knowledge economy. Taking a broad conception of the knowledge economy, the thesis emphasises the increasing importance of learning for competitiveness across multiple types of industrial activity. Specific attention is given to collaborative innovation processes, and the importance of geography in shaping such relations.

The thesis is based on the fundamental assumption that the concepts of knowledge, learning and innovation are central to the discipline of economic geography. The insights from economics that technological change and human capital drive economic growth (Solow, 1956; Arrow, 1962; Lucas, 1988; Romer, 1990), are of even greater importance in a globalised economy, where most production inputs become ubiquities due to time-space compression and trade liberalisation (Maskell and Malmberg, 1999b). As firms are unable to maintain competitiveness based on differences in labour cost, the Schumpeterian process of creative destruction (Schumpeter, 1942) forces firms to innovate at a continuously high pace. Thus, the ability to constantly identify, develop and combine heterogeneous forms of knowledge is crucial to the long-term profitability of firms.

In the contemporary knowledge economy, knowledge is the primary resource and learning is the most important process for acquiring this resource (Lundvall and Johnson, 1994). It follows from the increasing knowledge intensity of the economy and the faster diffusion of knowledge (Amin and Cohendet, 2004) that it is highly unlikely that organisations can access knowledge of a sufficient depth and variety within their own boundaries. Therefore, external relations of both formal and informal character are of essential importance for knowledge creation processes. A fundamental issue from both research and policy perspectives is the implications of these conditions for the geographical and sectoral organisation of the economy.

On *the geographical perspective*, contributions within economic geography and related disciplines have traditionally analysed the connection between geographical agglomerations and knowledge production, with a focus on the impact of geography in facilitating and influencing external relations. In the concept of localised learning, interactive knowledge creation is considered to be stimulated by localised capabilities and the ability to monitor and interact easily with other actors located in physical proximity (Maskell and Malmberg, 1999a; Malmberg and Maskell, 2002; 2006). Related views on knowledge creation through external relations are emphasised in theories on innovative *milieux* (Aydalot, 1988; Maillat and Lecoq, 1992), learning regions (Morgan, 1997; Benner, 2003), industrial districts (Brusco, 1982; Piore and Sabel, 1984) and clusters (Porter, 1990), which are all considered to be associated with fortunate characteristics such as high growth, competitiveness and resistance towards external chocks. The systemic character of innovation processes is most explicitly theorised in the concepts of national and regional innovation systems (Lundvall, 1992a; Edquist, 1997; Braczyk et al., 1998) which stress the importance of institutions and links to multiple types of actors within a geographically delimited area for innovation processes.

Concerning *the sectoral aspect*, scholars from a variety of social science disciplines emphasise the importance of restructuring the composition of the economy towards more research intensive industries. High-tech sectors[1] are considered to be vital to the economic recovery process in the advanced economies following the global financial crisis (Pisano and Shih, 2009), and the economic competitiveness of nations is compared by measuring the capabilities and performance of high-tech sectors (Newman et al., 2005). An associated body of literature analyses changes in research and development (R&D) investment levels (e.g. Van Reenen, 1997; Moncada-Paternò-Castello et al., 2010), which are also considered to be highly important for economic growth from a policy perspective (Sapir et al., 2003; European Commission, 2004). Thus, promoting high-tech industries through R&D investments is regarded as a main method for securing competitiveness in the knowledge economy (European Commission, 2008).

The foci on geographical agglomerations and high-tech industries converge in the vast amount of studies on clusters and agglomerations of high-tech firms (e.g. Saxenian, 1994; Audretsch and Stephan, 1996; Sternberg, 1996a; Capello, 1999; Kenney and von Burg, 1999; Frenkel, 2001; Meeus et al., 2001; Coenen et al., 2004; Cooke, 2004; Trippl et al., 2009; Klepper, 2010). One reason for this interest in high-tech clusters is that proximity is considered to be particularly important in research intensive industries (e.g. Huber, 2011), even though evidence is limited or even contradictory to this claim (see Martin and Moodysson, 2012). A further argument is that they are often considered the main source of competitive advantage for western countries. It is proposed that policymakers should focus on supporting high-tech regions rather than reducing inter-regional disparities in order to stimulate national competitiveness, and it is further suggested that such policies may benefit peripheral regions through (unexplained) trickle-down effects (Sternberg, 1996b).

In summary, unsurprisingly, the increasing importance of knowledge and learning for economic development has greatly influenced the work of scholars. How-

[1] The generally applied technological classification system is that of the OECD, based on the ratio of R&D expenditures to the output value of the individual industries, see OECD (2004).

ever, the conception of the knowledge economy that is proposed is often quite narrow. Thus, examining the heterogeneity of responses in knowledge sourcing and producing strategies to the changing conditions, may improve the understanding of developments in economic geography.

The thesis consists of six papers and a detailed summary (chapters 1-4); it is structured in the following way:

- The remaining part of chapter 1 presents the aim and contribution of the thesis as well as the content of the six papers.
- The theoretical framework is outlined in chapter 2.
- Methodological considerations are discussed in chapter 3.
- The main conclusions of the thesis are summarised and synthesised in chapter 4.

1.1. AIM AND CONTRIBUTION OF THE THESIS

The positions highlighted in the introducing section have dominated scholarly work within the last decades; however, they have been contested. Authors have highlighted the importance of non-physical proximity (Boschma, 2005), distanciated learning (Allen, 2000; Amin and Cohendet, 2004), and the ability of firms to source knowledge at various different scales, ranging from the local to the global (Wolfe and Gertler, 2004; Bathelt et al., 2004). Similarly, studies emphasise the continuing economic importance of low- and medium low-tech (LMT) industries in high-wage countries (Kaloudis et al., 2005), and the capabilities and measures that allow firms from these industries to maintain competitiveness (Bender and Laestadius, 2005; Von Tunzelmann and Acha, 2005; Hirsch-Kreinsen, 2008). Following these contributions, the aim of the thesis is *to examine the geographical and sectoral organisation of the knowledge economy*. This aim is approached from two perspectives, thus, the aim is broken down into two main parts:

A1. To study the impact of geographical proximity on interactive knowledge creation.

A2. To investigate the development of low- and medium low-tech manufacturing industries in high-wage countries.

The interest in these issues arises, firstly, from an academic interest in the relations between geography and other forms of proximity. The work of Boschma (2005), distinguishing between geographical, cognitive, organisational, social and institutional proximity has highlighted the advantages of a multidimensional perspective on proximity in external linkages, and thereby made a significant contribution to the debate on local and global knowledge flows. However, the position of geography in the framework is somewhat underdeveloped, as the variation in the importance of geographical proximity is not taken into account, and the possibility of substituting institutional, social, cognitive and organisational proximity for geographical proximity is emphasised rather than the indirect impact of geographical proximity on these other forms of proximity. Consequently, there is a need for studying the effects of geographical proximity on interactive knowledge creation in greater detail.

Secondly, the research interest results from what could be described as a mismatch between the focus of policymakers at both national and international levels, and the character of the real world economy. R&D investment levels do have a great impact on economic development, however, the attention that this measure receives in the policies of both the EU (European Commission, 2004; 2010) and national governments (e.g. The Danish Government, 2006) does not reflect the limited size of research intensive sectors relative to the total economy. R&D is not without importance in traditional industries such as food manufacturing, fabricated metal manufacturing, or publishing and printing, but demand side policies are considered of greater significance for these sectors (Edquist and Hommen, 1999; Von Tunzelmann and Acha, 2005). Therefore, considering the significant number of studies on development of high-tech industries as well as the attention given to these sectors by policymakers, research that highlights the innovation patterns and knowledge sourcing strategies of the 'silent majority' of manufacturing is needed in order to inform policymakers and allow the development of designated policies for these firms.

Finally, the research interest is also derived from a concern over the consequences of the increasing knowledge intensity of the economy and high-tech focused policies on the distribution of economic activity and the development of peripheral regions. Markusen (1996) has convincingly shown that national policy shifts towards high-tech industries are associated with increasing regional inequality, as economic development concentrates in the main metropolitan regions. Amin and Tomaney (1995) make a similar point concerning the changing focus of EU competitiveness policies. Only few regions have the characteristics that give them the opportunity to attract economic activity within research intensive domains (Malecki, 2004; Perry and May, 2007). Thus, analysing the opportunities and limitations for economic development in peripheral areas given the changing character of the economy is of considerable importance to the extent that geographically balanced growth remains a policy priority. This issue is closely linked to the topic of development of LMT industries, as they are of particular economic significance for peripheral regions.

On the basis of these aims and fields of interests, the thesis seeks to answer a number of interrelated research questions. The following three research questions are in particular related to *A1: To study the impact of geographical proximity on interactive knowledge creation.*

RQ1. *How is geography related to institutional, social, cognitive and organisational proximity dimensions in interactive innovation projects?*

RQ2. *How can variation along proximity dimensions in interactive innovation projects be explained?*

RQ3. *Does changing geographical proximity alter collaboration patterns?*

The following three research questions are primarily related to *A2: To investigate the development of low- and medium low-tech manufacturing industries in high-wage countries.*

RQ4. *How is the economic performance of low- and medium low-tech manufacturing industries in high-wage countries?*

RQ5. *Which innovation strategies do low- and medium low-tech manufacturing firms follow to maintain competitiveness?*

RQ6. *What is the importance of human capital in low- and medium low-tech manufacturing industries?*

The research questions examine the knowledge economy from two different perspectives. The approaches are distinct, but the research questions in the two parts are nevertheless interrelated (see also section 4.3). For instance, interactive knowledge creation is highly important for the innovative capacity of LMT firms. The following section of this introductory chapter describes the papers included in the thesis and explains how the research questions are addressed.

1.2. Papers included in the thesis

The summary of the thesis is followed by six papers which all examine aspects of the geographical and sectoral organisation of the knowledge economy. Each of the papers addresses one or more of the formulated research questions. The first three papers deal specifically with the importance of geographical proximity for interactive knowledge creation, while the following three papers analyse the position of LMT industries in the knowledge economy.

Table 1. Overview of the contributions of the papers

	Research questions covered	Empirical foundation	Analytical approach
Paper I: Substitution or overlap? The relations between geographical and non-spatial proximity dimensions in collaborative innovation projects	RQ1	50 interviews	Primarily quantitative
Paper II: Juggling with proximity and distance. Collaborative product development in the Danish cleantech industry	RQ2	50 interviews	Qualitative
Paper III: Cross-border innovation – regional integration in the Øresund Region 1994-2009	RQ3	Bibliometric data (Science Citation Index Expanded)	Quantitative
Paper IV: Innovation, regional development and relations between high- and low-tech industries	RQ4, RQ5	31 interviews. Employment and value added data (STAN database, OECD)	Primarily qualitative
Paper V: The Danish fabricated metal industry: A competitive medium-low-tech industry in a high-wage country	RQ4, RQ5	20 interviews. Employment and value added data (RAS and NAT databases, Statistics Denmark)	Primarily qualitative
Paper VI: Human Capital in Low-Tech Manufacturing: the Geography of the Knowledge Economy in Denmark	RQ6	Employment data (RAS database, Statistics Denmark)	Quantitative

The different character of the research questions implies that the papers analyse processes at various spatial levels. Papers I and II study external partnerships at all scales, ranging from the local to the global. Paper III has a focus on collaborations at the regional scale and in particular the Øresund cross-border region between Denmark and Sweden. However, the paper also examines relations to other major city regions and thereby compares the regional processes to developments at a higher geographical scale. Papers IV and V present case studies of innovation strategies among firms in a specific Danish region. Paper IV also draws upon empirical material from a comparable British region. Finally, paper VI examines the distribution of human capital in different types of industries on the basis of Danish data at the municipality level. The paper has a specific focus on differences between peripheral and urban parts of Denmark.

The six papers analyse different types of industrial sectors. Papers IV and V deal with LMT industries: paper IV with the fabricated metal and plastics industries; paper V only with the fabricated metal industry. Paper VI has not an empirical focus on a particular industry, but it shares the theoretical focus on LMT industries with papers IV and V. Paper III gives particular attention to a high-tech sector: the biotech industry. Papers I and II are concerned with the cleantech industry which is not an independent industry in standard industrial classifications. Thus, it cannot be classified as a low-, medium- or high-tech industry, but includes elements from each of the different categories in this taxonomy – from the highly R&D-intensive development of fuel cell technologies to R&D-extensive activities such as the production of many wind turbine components. While some of the papers (in particular paper VI) contrast developments within low-, medium- and high-tech industries over time, it is not the ambition of the thesis to present a detailed comparison of the positions of these industries in the knowledge economy. Rather, the objective is to examine diverse aspects of the knowledge economy and emphasise that it is not confined to R&D-intensive industries. Before proceeding to the theoretical background of the thesis, the six papers are introduced in greater detail below.

Paper I: Hansen, Teis (2012): Substitution or overlap? The relations between geographical and non-spatial proximity dimensions in collaborative innovation projects. *Submitted to a journal, August 2011. In revised version, May 2012.*

Paper I aims to contribute to the debate on the relation between, on the one hand, geography and, on the other hand, institutional, social, cognitive and organisational dimensions of proximity. It is argued in the paper that this debate revolves around the relative importance of two mechanisms: the substitution mechanism, where institutional, social, cognitive and organisational proximity substitute for geographical proximity, and the overlap mechanism, where geographical proximity facilitates these other forms of proximity. The importance of these two mechanisms is analysed in the case of collaborative product development projects in the Danish cleantech industry. Ordered logit models are applied to data on collaborations compiled through interviews with 50 firms, and supplemented with a qualitative analysis focusing on the relationship between the geographical and institutional dimensions.

Paper II: Hansen, Teis (2012): Juggling with proximity and distance. Collaborative product development in the Danish cleantech industry. *Submitted to a journal, March 2012.*

The purpose of paper II is to analyse variation in the characteristics of collaborations according to the five dimensions of proximity, as previous research has paid insufficient attention to this issue. Paper II is based on the same empirical material as paper I, however, it is analysed qualitatively in this paper. Drawing on organisational theory on partnership formation, the paper explores how collaboration objectives influence the variation along the proximity dimensions in partnerships. In this way, the analysis distinguishes between the types of collaborations where geographical proximity is highly important, and those where institutional, social, cognitive and organisational proximity may substitute for it.

Paper III: Hansen, Teis (2011): Cross-border innovation – regional integration in the Øresund Region 1994-2009. *Submitted to a journal, October 2011.*

Paper III is concerned with the relation between changes in geographical proximity and collaboration patterns. Specifically, the paper addresses the effect of the construction of the fixed link between Denmark and Sweden on collaboration in the Øresund Region. Focusing on research partnerships, the analysis examines the development over time in collaborations between actors from the Danish and Swedish sides of the cross-border region. Based on data from Science Citation Index Expanded on co-authorships, the paper analyses both the quantity and quality of cross-border co-authorships in the years before and after the abrupt reduction in transportation time between the Danish and Swedish parts of the Øresund Region.

Paper IV: Hansen, Teis & Winther, Lars (2011): Innovation, regional development and relations between high- and low-tech industries. *European Urban and Regional Studies*, Vol. 18 (3), Pp 321-339.

Paper IV critically considers the policy focus of the European Union (EU) on R&D as a driver of economic growth. The arguments in favour of such a policy are examined, based on employment and value added data for different types of industries over time in 12 European countries. Further, the paper seeks to advance the understanding of the factors that allow LMT firms in high-wage countries to maintain competitiveness, by focusing on relations between low- and high-tech firms. This part of the paper is based on interviews with Danish and British firms and organisations from the fabricated metal and plastics industries. Finally, the consequences of the EU policy focus on regional inequality in Europe are discussed in light of the findings of the analysis.

Paper V: Hansen, Teis (2010): The Danish fabricated metal industry: A competitive medium-low-tech industry in a high-wage country. *Danish Journal of Geography*, Vol. 110 (1), Pp 65-80.

Similarly to paper IV, the point of departure for paper V is an analysis of the development of employment and value added over time for different types of industries, here at the Danish national level. Where paper IV subsequently focused on the interconnectedness of low- and high-tech industries, paper V deals with innovation processes in non-R&D intensive industries. This analysis draws on interviews with representatives from Danish fabricated metal firms which highlight the importance of different types of innovation strategies. Finally, the possibilities of supporting such innovation strategies through policymaking are discussed.

Paper VI: Hansen, Ronnie F.; Hansen, Teis & Winther, Lars (2012): Human Capital in Low-Tech Manufacturing: the Geography of the Knowledge Economy in Denmark. *Submitted to a journal, April 2012.*

Paper VI is concerned with an additional aspect of the development of LMT industries, namely the role of human capital. Multiple studies have confirmed the importance of highly skilled labour for high-tech industries, and human capital is often considered particularly significant to these industries by academics and policymakers. Based on Danish employment data covering the period 1993-2006, this paper analyses the use of human capital over time in LMT industries, compared to industries with higher R&D intensity. Furthermore, the changing geographical concentration of highly skilled workers is explored for the different types of industries.

2. THEORETICAL BACKGROUND

This chapter presents the theoretical foundations of the thesis. The specific theoretical frameworks for each of the six papers are not outlined here – they are to be found in the opening sections of the individual papers. Rather, the intention of this chapter is to introduce the general theoretical background, within which the papers seek to contribute, and the most central theoretical concepts. Further, some reflections which are not included in the papers, due to length constraints, are presented here. The point of departure is an understanding of current society as significantly shaped by knowledge and capabilities.

2.1. SETTING THE SCENE: THE KNOWLEDGE ECONOMY

In the knowledge society, as termed by Bell (1973) and Drucker (1993), knowledge is the central structuring component: from the individual level, where increasing reflexivity, understood as the recurrent use of knowledge, is shaping everyday life and practices (Giddens, 1990), to the system level, where knowledge plays a fundamental role in explaining the functioning of the economy (Bell, 1973). As indicated by the titles of Bell's (1973) and Drucker's (1993) books – respectively *The Coming of Post-Industrial Society* and *Post-Capitalist Society* – this development is associated with a transition from a fordist production system, where capital plays a crucial role, to a post-fordist system, where knowledge is the essential resource. Closely related to this, is an increasing focus on the embodiment of knowledge, i.e. human capital, knowledge workers and talents (Lucas, 1988; Romer, 1990; Reich, 1992; OECD, 1998; Florida, 2002).

It is worth noting that codification[2] of knowledge is the central feature of the transition towards a knowledge economy, according to Bell (1973). This emphasis is also found in the more recent influential contributions by David and Foray, (1995; 2002). In their work on the knowledge-based economy, they recognise the importance of tacit knowledge and argue that all economically relevant knowledge depends on both tacit and codified elements (see below, section 2.3). Still, they reject a broad analytical perspective on knowledge that includes all aspects of relevance for economic activity. Rather, they emphasise scientific and technological knowledge, and the importance for economic development of science-driven sectors, characterised by a high degree of codification of knowledge. Thus, the knowledge-based economy is closely related to high-tech industries and investments in R&D (OECD, 1996; see also Coenen et al., 2004).

[2] Codification is here defined as the process of converting, formalising and storing knowledge, which was previously difficult to communicate due to its unarticulated character, through a code of translation (i.e. reducing the tacitness of knowledge). See also Balconi et al. (2007).

In comparison, the concept of the learning economy, as presented by Lundvall and Johnson (1994), stresses the economic importance of different forms of knowledge to a greater extent. Learning, understood as the process of creating and disseminating knowledge, is found to be increasingly pervasive, heterogeneous and significant in all aspects of economic activity. Consequently, Lundvall and Johnson (1994) emphasise that the increasing importance of learning is not confined to high-tech industries, but a general feature of the contemporary economy. Thus, while a key feature of the learning economy is the emergence of new science-based industries, an equally important feature is the changing learning processes in traditional industries.

In this way, there are clear differences between the foci in the pure versions of the theories on the knowledge-based economy and the learning economy; however, the distinction is blurred in other contributions where the approaches are combined, e.g. Lundvall and Foray (1996).[3] This has led Smith (2002, p. 1) to pose the question *"What is the knowledge economy?"* In this thesis, the term 'the knowledge economy' is applied and understood as a result of the faster diffusion of knowledge due to advances in information and communication technologies and the increasing long-term knowledge intensity of the economy (Amin and Cohendet, 2004). Although it should be remembered that the economy has always depended on knowledge (Hudson, 2009), the knowledge economy is in particular characterised by the increasing pace of creative destruction processes (Schumpeter, 1942) that forces firms to, firstly, constantly employ new knowledge in their activities and, secondly, combine different types of knowledge to a greater extent. While acknowledging the importance of science as a driver of economic development (Dasgupta and David, 1994), this understanding of the knowledge economy does not concur with the focus on scientific and technological knowledge in the writings on the knowledge-based economy. The perspective is closer to the description of the learning economy, as it is presented in Lundvall and Johnson (1994). Still, the term 'the knowledge economy' is preferred in this thesis, as it is broadly used across the social sciences, from economic history (Mokyr, 2002) to organisation studies (Adler, 2001) and economic geography (Cooke, 2001).[4]

Thus, in the knowledge economy, the acquisition, creation and utilisation of knowledge is the key factor explaining competitive advantage, as firms must continuously innovate to maintain market shares and profit levels (Nonaka, 1994;

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[3] As indicated by the title: *The knowledge-based economy: from the economics of knowledge to the learning economy*. See also the critique by Godin (2006).

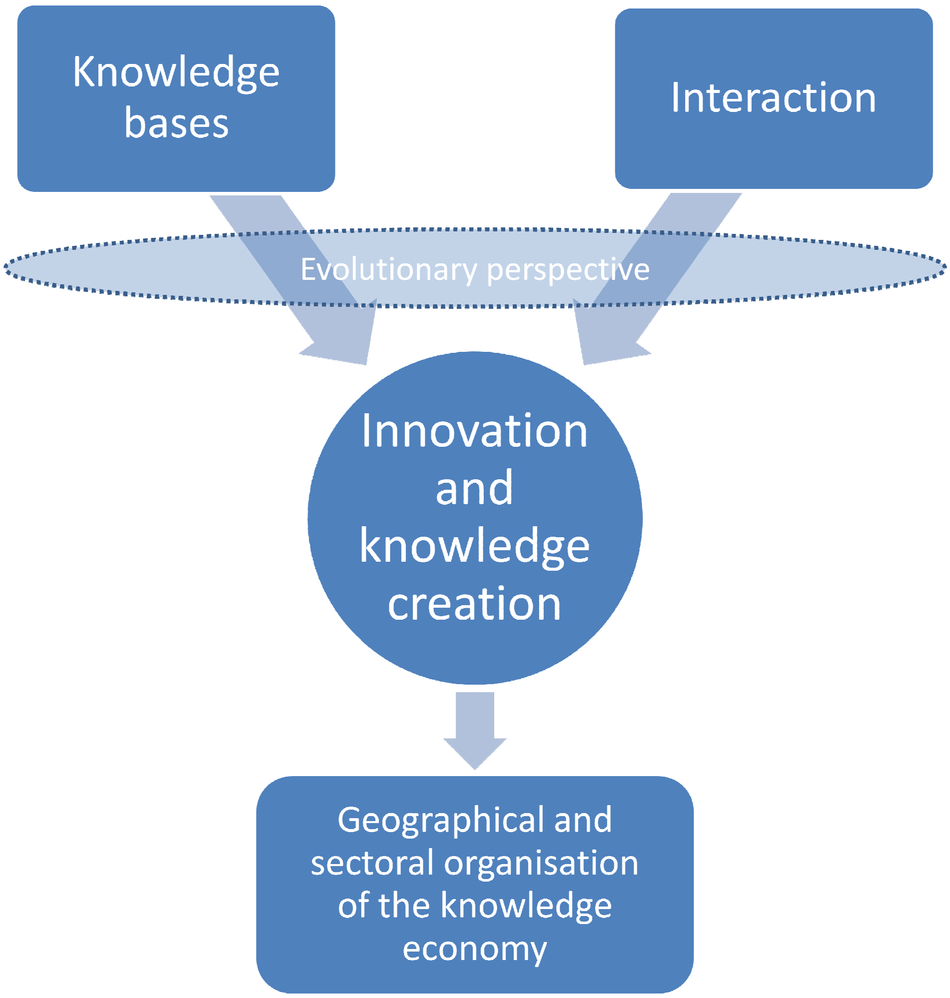
[4] This is not to say that "the knowledge economy" is unproblematic as a term. It is applied in diverse ways, some of which are very close to "the knowledge-based economy" (e.g. Powell and Snellman, 2004).

Lawson and Lorenz, 1999; Maskell and Malmberg, 1999b). In this way, it is not just the knowledge creation in itself that is important, but also the ability to capitalise on knowledge. In this thesis, the analysis of innovation processes emphasises the relations between actors, rather than a fully systemic approach (Lundvall, 1992a; Edquist, 1997; Braczyk et al., 1998; Cooke, 2001; Asheim et al., 2011b). This is not to question that the relations are embedded in a system; in fact, innovation system theory is part of the conceptual framework of paper III.[5] However, departing from the innovation system approach and focusing on relations (as e.g. in paper II) increases the analytical clarity by abstracting from a number of influences.

A second emphasis of the thesis concerns the type of relations. The analysis focuses on dynamic relations characterised by mutual learning rather than e.g. market based relations (see Trippl et al., 2009). However, the categories do overlap in some instances, exemplified by the importance of customer relations for LMT innovation processes (paper V), or the practice of collaborating with specific partners in product development projects in order to access new markets (paper II). Still, the emphasis is first and foremost on relations where considerable activity revolves around knowledge creation and innovation.

[5] See also section 2.4 on the influence of government policy on partnership formation.

Figure 1. Summary of general theoretical framework



Based on these reflections, figure 1 summarises the general theoretical framework of the thesis. Acknowledging the central and increasing role of knowledge in the economy implies that understanding processes of knowledge creation and innovation are essential to any examination of the geographical and sectoral organisation of the economy. The remaining sections of chapter 2 outline the theoretical perspectives that are applied in the thesis to understand this issue. Fundamentally, knowledge creation and innovation are considered *evolutionary processes* shaped by the resources and routines of firms (section 2.2). A neoclassical perspective, based on equilibrium theory, is inappropriate to understand knowledge creation and innovation which are dynamic processes shaped by history, rather than static processes. Capitalism constitutes a selection environment where constant innovation is necessary to survive, and an evolutionary perspective is therefore applied to understand the developments of this system. The concept of *knowledge bases* is used in order to comprehend differences between industries in the types of knowledge applied (section 2.3). The character of innovation and knowledge creation processes vary significantly, depending on inter-industrial differences between the types of knowledge that are crucial for economic activity. Further, the *interactive character* of innovation and knowledge creation processes is stressed (section 2.4). It follows from an understanding of such activities as collaborative processes that it is particularly interesting to examine the characteristics of these relations. The *proximity dimensions framework* is applied to grasp the mechanisms that shape collaborative knowledge creation and innovation processes, and in particular the role of geography (section 2.5).

2.2. An evolutionary perspective

According to Nelson (1995), evolutionary theories share three core principles: they (1) explain the movement of something over time, by (2) considering random elements that generate variation and mechanisms that systematically eliminate among the existing variants, and (3) stress the existence of inertial forces that ensure continuity among the surviving variants. Along similar lines, Campbell (1974, p. 421) describes the key characteristics of evolution theory as *"(a) Mechanisms for introducing variation; (b) consistent selection processes; and (c) mechanisms for preserving and/or propagating the selected variations."* In Darwin's theory, these different mechanisms depend on (a) mutations, (b) natural selection and (c) genes.

Building on the writings of Schumpeter (1942), the seminar work of Nelson and Winter (1982) has been central in the promotion of evolutionary theory within economics.[6] Here, the three mechanisms are (c) routines, (a) search for new and fitter routines and (b) the selection environment. Ontologically, evolutionary economics is clearly distinct from mainstream neoclassical economics as it rejects the view of the economy as a closed system and argues that technological change is to be at the centre of economic analysis. This emphasis on novelty and unforeseen change is fundamentally at odds with equilibrium theory, as diminishing profits due to price competition (moving towards equilibrium) is only a secondary dynamic in comparison with innovation processes and the search for innovation rents (moving away from equilibrium) (Foss, 1994; Boschma and Frenken, 2006).

Inspired by evolutionary economics, an evolutionary economic geography framework has recently been developed (Boschma and Frenken, 2006; 2009; 2011; Boschma and Martin, 2007; 2010). While the concept of evolution was not

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[6] Further, Nelson and Winter's (1982) concept of routines seems to draw considerably on the emphasis on firm-specific competences resulting from prior experience in Penrose (1959), yet, they only acknowledge her contribution once (p. 36). However, some evolutionary economic geographers (e.g. Stam, 2007; 2010) highlight the close relation between firm routines and the Penrosean theory of the firm.

completely absent in the economic geography literature prior to this work (see e.g. Rigby and Essletzbichler, 1997; Essletzbichler and Winther, 1999; Martin, 2000; Winther, 2001; Essletzbichler and Rigby, 2005), the ambition of Boschma and colleagues has been to clearly define a theory of evolutionary economic geography, complete with research methodology and research agenda. Following Nelson and Winter (1982), the outset of Boschma and Frenken (2006) is to view routines and their development over time as the key parameter for competitive selection among firms. The aim of evolutionary economic geography then is to analyse the changing spatial distribution of routines and the resulting impact on the distribution of economic activity – *"the 'creative destruction' of economic landscapes"* (Boschma and Martin, 2007, p. 539).

Summarising, the evolutionary perspective is applicable for analysing economic processes at different levels. At the micro-level, the analytical object is routines and their development. It follows that attention must be given to the strategic choices of actors which introduce variation to the system. This focus is in particular prominent in the analysis of partner selection in collaborative product development projects presented in paper II. At the meso-level, the evolutionary perspective highlights that economic development of sectors and areas depend on the actions of micro-level actors which are shaped by history and previous experience.[7] This focus is especially pronounced in papers IV and V which highlight how the continuity in the industrial structure is shaped by the ability of LMT firms to maintain competitiveness through a combination of traditional, inherited capabilities and external knowledge inputs from e.g. high-tech industries.

2.3. Knowledge and knowledge bases

Often, knowledge is defined relative to information. The definition of *information* as structured data is generally accepted. However, economists have often understood *knowledge* as a stock of information, thus, making the distinction between the two terms nearly unnecessary, but this definition has been widely criticised elsewhere (e.g. Ancori et al., 2000). Recent contributions by economists highlight the encounter between information and cognition, defining knowledge as "*the label affixed to the state of the agent's entire cognitive context*" (Cowan et al., 2000, p. 216). This definition rejects the simplistic view of knowledge as accumulated information, but has been criticised for maintaining a view of knowledge as a per-

[7] The evolutionary perspective is highly sensitive to the historical dimension of economic development, but has an inherent risk of understating the role of institutions; see section 3.2 for more on this.

sonal attribute (Balconi et al., 2007).[8] Echoing Howells' (2002) description of knowledge as a socially constructed process, knowledge is defined as a process and practice rather than a possession by Amin and Cohendet (2004). Thus, knowledge exists between rather than within individuals (Lam, 2005). This is the definition of knowledge applied in this thesis. It follows that the analysis of the knowledge economy must be particularly sensitive to the interactive character of knowledge, including the geographical aspects of this interaction.

The disagreement concerning the definition of knowledge is linked to different opinions concerning the ability to codify tacit knowledge. Firstly, the understanding of knowledge as a stock of information assumes that all knowledge can be articulated and communicated through a code of translation (i.e. it can be *codified*). However, it follows directly from Polanyi (1966) that information and knowledge are different concepts if it is accepted that it is very difficult or even impossible to articulate and communicate some knowledge (that is, it is *tacit*). Secondly, as emphasised by Nelson and Winter (1982), tacit knowledge often take the form of organisational routines, implying that this knowledge is distributed beyond single individuals.

Before proceeding to the knowledge base approach, the relation between knowledge and *innovation* is considered. According to Pavitt (2005), innovation processes contain three overlapping sub-processes: production of knowledge, conversion of knowledge into artefacts, and the matching of these artefacts to market needs and demands. Therefore, all innovation processes rest upon acquisition, creation and utilisation of knowledge which is introduced on the market. Importantly, knowledge creation and acquisition does not constitute a preliminary stage in the innovation process, but is occurring throughout the innovation process, cf. the critique by Kline and Rosenberg (1986) of the linear model of innovation (Bush, 1945).

The knowledge base approach, as it is developed in the work of Asheim and colleagues (Coenen et al., 2004; Asheim and Gertler, 2005; Asheim and Coenen, 2005; 2006; Asheim, 2007; Moodysson et al., 2008; Moodysson, 2008; Asheim and Hansen, 2009; Asheim, 2011; Asheim et al., 2011a; Martin and Moodysson, 2012), emphasises inter-industrial differences in processes of knowledge creation and utilisation.[9] Thus, the analytical focus is on the characteristics of the knowl-

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[8] Cowan et al. (2000) do in fact acknowledge the role of collective activities and collective memory in later sections of the paper. However, this is not reflected in the definition.

[9] To clarify: the knowledge base approach (Asheim, 2007) is not associated with the writings on the knowledge-based economy (David and Foray, 1995; 2002). In fact, the knowledge base approach is exactly highlighting the importance of different types of knowledge creation proc-

edge that is crucial for economic activity in different industries, that is, *the knowledge base*. An important characteristic of the knowledge base approach is that it seeks to *"transcend the simple dichotomy of tacit-codified knowledge"* (Moodysson, 2007, p. 34). While maintaining that the tacit/codified dichotomy is one of several important dimensions separating the different knowledge bases, the knowledge base approach takes the critique of the overemphasis on this distinction into account (e.g. Johnson et al., 2002). Rather, the point of departure is taken in a distinction between *analytical*, *synthetic* and *symbolic* types of knowledge introduced by Laestadius (1998). Following this, Asheim and Gertler (2005) and Asheim (2007) describe the three knowledge bases as, respectively, science based, engineering based and art based. While all industries rely on combinations of these types of knowledge (see e.g. Moodysson, 2008), the knowledge base approach should be understood as a framework which can be used to identify the knowledge that is critical to innovation processes. Innovation processes are, in some industries, driven by theoretical and universal knowledge (analytical knowledge base), in other industries, founded on instrumental and context specific knowledge (synthetic knowledge base), and in a third type of industries, aesthetic and cultural knowledge (symbolic knowledge base).

Naturally, the differences between the knowledge bases have significant implications for the nature of knowledge creation processes (Asheim, 2007). A key feature of the *analytical knowledge base* is the use of scientific methods and modelling. Codified knowledge is a major input as well as a major output of the knowledge creation process, and links to universities and research institutions are therefore crucial to the innovativeness of firms with analytical knowledge bases. Innovations are often radical, contrary to innovations in industries with *synthetic knowledge bases* which are predominantly incremental. These firms primarily utilise existing knowledge in new product and process developments, and tacit knowledge acquired through learning by doing and learning by using is therefore central to innovation processes. While links to knowledge institutions can be of importance, especially within the field of applied research, up- and down-stream relations are in particular significant, as innovation projects often revolve around customer specific problems. Finally, the *symbolic knowledge base* is associated with industries where the value creation depends on the production of immaterial characteristics – e.g. ideas, images and symbols. Networking, creativity and social skills are more relevant than formal education and certified qualifications for such firms, as the knowledge creation process is often very context dependent. These innovation processes require tacit knowledge concerning the everyday

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esses, while the scientific and technological knowledge is the focus of the work on the knowledge-based economy.

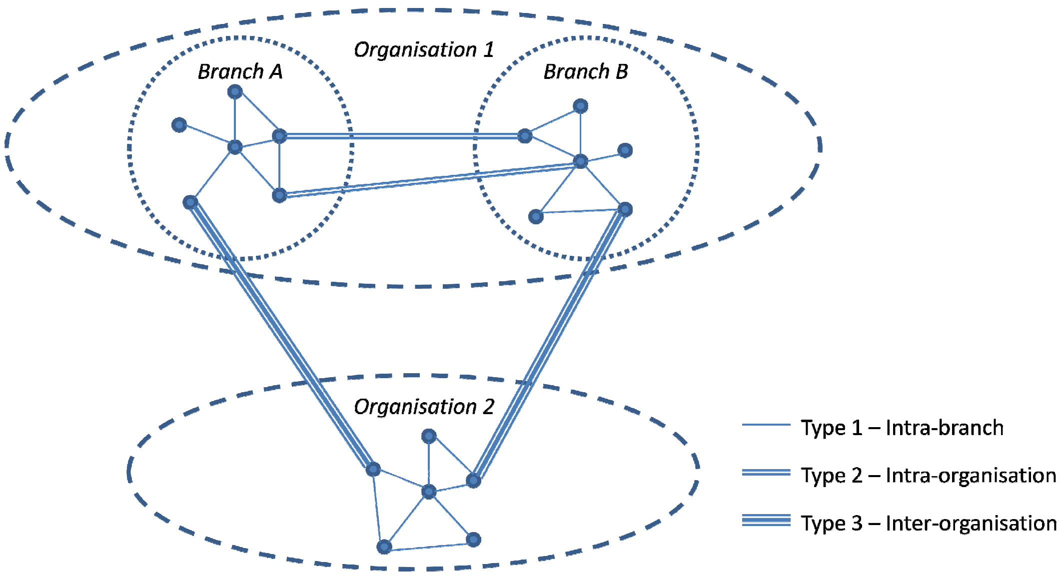
habits and norms of certain groups, and the projects are often carried out in intense collaborations of limited duration with external partners.

The knowledge base approach is particularly a central part of the theoretical framework in the papers dealing with LMT innovation strategies (papers IV and V) as it highlights inter-sectoral differences in knowledge creation processes. Thus, applying the concept of knowledge bases improves the understanding of the foundation of LMT innovation processes, as they have been described in a number of recent contributions (Radauer and Streicher, 2007; Hirsch-Kreinsen, 2008; Chen, 2009; Kirner et al., 2009; Santamaria et al., 2009; Trippl, 2011). Further, the concept is also included in papers I (as a control variable) and III (to explain the industrial context), as it follows from the descriptions of the three types of knowledge bases that there are great differences between the significance of different types of external linkages. The importance of different partner types is one aspect, and Martin and Moodysson (2012) show that the sensitivity to geographical distance in inter-organisational knowledge creation processes also depends on the knowledge bases of industries: global networks are particularly important for firms in the life science industry (analytical knowledge base), national and regional networks are essential in the food industry (synthetic knowledge base), and local networks are crucial in the moving media industry (symbolic knowledge base). Thus, the knowledge base is an important factor to take into account when analysing the influence of geography on interactive knowledge creation.

2.4. Interactive knowledge creation

An analytical focus on interactive knowledge creation follows from the definition of knowledge as a socially constructed process where knowledge exists between individuals. Figure 2 underlines that such interactions take place at different levels: intra-branch (type 1), intra-organisational (type 2) and inter-organisational (type 3)

Figure 2. Types of linkages in interactive knowledge creation



This thesis focuses primarily on type 3, and to a lesser extent on type 2. This is not to suggest that interactions at the workplace are of minor importance for knowledge creation (see e.g. Freel, 2003; Arundel et al., 2007). However, academic interest in firm networks and collaborations has increased substantially in the last decades (see Grandori and Soda (1995), Powell and Grodal (2005) and Ozman (2009) for literature reviews), reflecting the increasing importance of such relations for knowledge creation. The growing knowledge intensity and technological complexity of the economy, as well as the faster diffusion of knowledge, necessitate collaborations to access diverse competences (Powell et al., 1996; Amin and Cohendet, 2004). Further, while specialisation allows firms to build focused and unique expertises, truly successful innovations often result from combining diverse bodies of knowledge. Thus, interactive knowledge creation is a fundamental and increasingly important element of knowledge creation processes.[10]

The increasing specialisation and focus on core competences is associated with a growing importance of projects as an organisational practice. The work of Grabher (2002a; 2002b; 2004; 2006) has in particular unveiled the characteristics of this organisational form in an economic geography context. Rather than

[10] It should be noted that evidence indicates that interaction can also be too intense. It is costly for firms to collaborate, suggesting an inverted U-shaped relation between number of collaborations and innovative capacity (Cantner et al., 2010). Thus, network centrality and low tie redundancy are crucial aspects, highlighting the importance of selective and strategic networking (Hagedoorn et al., 2006).

viewing temporary projects as a substitute for permanent organisational forms such as firms, Grabher explores the interdependencies of organisational forms and terms the resulting organisational and physical space *the project ecology*. In this thesis, Grabher's work contributes to the theoretical framework in several ways. Firstly, the notion of the project ecology is highly sensitive to the importance of combining diverse competences across different organisations on a temporary basis. Thus, the need for flexibility and the ability to reconfigure the project set-up is stressed. Secondly, Grabher's attention to projects is an important supplement to the general literature on inter-firm collaborations which has primarily dealt with long-term contractual partnerships and research joint ventures (see Hagedoorn et al., 2000). Thirdly, Grabher deals specifically with the geographical aspects of project-based work (this topic is treated in the following section 2.5).

Interactive knowledge creation is a central element in most of the thesis' papers (in particular papers I, II, III and IV, to a lesser extent paper V). The papers emphasise to varying degrees processes of partner selection. In particular paper II focuses on how firms choose different partners, depending on the motives for engaging in collaborations. This paper takes collaboration objectives as the outset for understanding partnership formation, thus, little attention is given to the importance of structural factors. However, it should be stressed that not all firms have equal possibilities to choose between different collaboration partners (Gulati, 1995). A large number of factors act as filters in the selection process, making some options unlikely or unfeasible. Therefore, the impact of technical capital, social capital, firm size, geographical location and government policy are considered in the following paragraphs.[11]

Technical capital, defined as a firm's capabilities in creating new technology, products and processes, has a significantly positive influence on the ability to form partnerships (Ahuja, 2000). Previously successful innovation projects increase the credibility of the firm and promote it as an attractive partner in the eyes of external actors (Stuart, 1998). Therefore, hiring star scientists not only increases the internal research capacity, but also improves the ability to form external partnerships (Audretsch and Stephan, 1996; Luo et al., 2009). Further, as highlighted by Cohen and Levinthal (1990), part of the positive impact of absorptive capacity[12] on learning is due to the ability to identify and evaluate new rele-

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[11] Other factors such as the position in firm and industry life circles and the behaviour of lead firms also influence the selection process of partners (Ozman, 2009), however, the five selected factors have in particular been analysed in the literature.

[12] The use of the concepts of technical capital and absorptive capacity are dissimilar, but related. While Ahuja (2000) analyses the effect of technical capital (measured by number of

vant technologies. Thus, without the appropriate level of absorptive capacity, a firm may not realise the potential of engaging in a certain external partnership.

The social embeddedness of economic activity (Granovetter, 1985) has been emphasised in multiple studies of inter-organisational partnerships. The work of Gulati (1995; 1998) has in particular been influential in stressing how social networks facilitate partnership formation by, firstly, providing information on appropriate collaborators at the right time and, secondly, reducing the risk of opportunistic behaviour. Importantly, these effects result from both direct and indirect ties. Mechanisms of referrals and sanctions which enhance trustworthy behaviour work beyond immediate ties in the network. Consequently, partnerships are often created between former collaborators or firms with a shared connection (Gulati, 1995; Mowery et al., 1998; Guimerà et al., 2005; Autant-Bernard et al., 2007; Paier and Scherngell, 2011). Thus, it is difficult for firms outside of the network to enter, but the development of radical innovations may act as admission tickets to the network through subsequent research and development (R&D) alliances (Powell et al., 1996; Ahuja, 2000). Alternatively, firms may recruit people with experience from top management positions in the industry or participate in committee activity in trade associations, as these strategies also positively influence the ability to form networks (Eisenhardt and Schoonhoven, 1996; Rosenkopf et al., 2001).

The location of firms in space is an additional factor that influences the ability of firms to form partnerships. As few studies explicitly apply an *"accessibility to knowledge"* perspective (Massard and Mehier, 2009, p. 77) on collaborative innovation projects, there is a need to improve the understanding of geography's impact on the opportunity to form links (Massard, 2011). However, evidence suggests that proximity to universities does indeed facilitate knowledge flows (Andersson and Ejermo, 2005). Thus, on the one hand, for firms with limited resources located in peripheral areas, such interactions can be either out of reach or too expensive to initiate. Further, these firms might find it difficult to recruit highly-skilled labour with well-developed networks that can facilitate collaboration. On the other hand, firms from such areas with abundant resources are likely to collaborate over longer distances than firms in core regions, as the available inputs are often not available locally (Feldman, 1994; Drejer and Vinding, 2007).

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patents) on the ability to form partnerships, Cohen and Levinthal (1989; 1990) examine the impact of absorptive capacity (measured by R&D spending) on learning and innovation. Thus, they deal with both the ability to identify and form the right partnerships as well as capacity to benefit from them, while Ahuja (2000) focuses on the first of these themes (see also Grimpe and Sofka, 2009).

In this way, geographical location impacts the extent and character of firm interactions.

Compared to the other factors, evidence of the effect of firm size on partnership formation is inconclusive. While some results point towards a positive effect of firm size (e.g. Rosenkopf et al., 2001; Hagedoorn et al., 2006), other studies find no effect (e.g. Eisenhardt and Schoonhoven, 1996; Stuart, 1998). In accordance with the latter position, Powell et al. (1996) find that centrality in collaboration networks facilitates firm growth – not vice versa. Similar to the results of Mowery et al. (1996), who show that large firms are unable to absorb as many capabilities from strategic alliances as smaller firms, these conclusions provide some caution against the hypothesis that, *ceteris paribus*, large firms have the greatest possibility to benefit from external networks.

Finally, government policy also has an important influence on firm partnership formation. Firstly, the availability of public funding for R&D increases the probability of engagement in collaborative projects, in particular in the precompetitive stage of development (Arranz and de Arroyabe, 2008; Rothgang et al., 2011; Matt et al., 2011). Secondly, the selection criteria have significant impacts on partnership formation. The condition of multinational collaboration in projects supported by the EU Commission exemplifies this, even though such policies do not completely eliminate the importance of geography in the selection of partners (Paier and Scherngell, 2011). Furthermore, it should be noted that the impact of such policies is found to be of particular importance in the longer run, beyond the duration of the individual projects that receive funding (Defazio et al., 2009).

Summing up, interactive knowledge creation is of crucial and increasing importance for the innovativeness of firms. Growing knowledge intensity, technological complexity, specialisation and emphasis on core competences imply that engagement in external relations through e.g. temporary projects is increasingly an essential activity. Thus, understanding the characteristics of partnerships and the rationale for selecting particular partners in particular situations are key research issues. Additionally, the role of geography in this relation is naturally of significant interest to economic geographers. This is considered in the following section.

2.5. Geography and proximity in interactive knowledge creation

The geography of interactive knowledge creation has been a key issue in economic geography during the last decades. In addition to agglomeration effects, which do not necessitate interactions between localized actors, numerous contributions highlight the impact of geographical proximity in facilitating and stimulating interactions between different types of actors (Knoben, 2009). Interactive knowledge creation is an important element in the various territorial innovation models, from innovative *milieux* (Aydalot, 1988; Maillat and Lecoq, 1992) to learning regions (Morgan, 1997; Benner, 2003), industrial districts (Brusco, 1982; Piore and Sabel, 1984) and clusters (Porter, 1990), even though the precise character of the type of interaction vary from one model to the other.[13] Thus, localised capabilities and the ability to monitor and interact easily with other actors located in physical proximity are considered central to the understanding of interaction patterns (Storper, 1997; Maskell and Malmberg, 1999a; Malmberg and Maskell, 2002; 2006).

In this way, it is beyond doubt that geographical proximity has a positive effect on trust creation and information transfer through the possibility of easy and frequent face-to-face contact (Storper and Venables, 2004). Thus, it is a reasonable argument that geographical proximity positively influences interactive knowledge creation (Howells, 2002; Morgan, 2004); however, two unfortunate and related consequences have followed from this insight. Firstly, some contributions focus on localised knowledge spillovers without considering the actual relations whereby knowledge is created and diffused (Jaffe et al., 1993; Camagni, 1995; Audretsch and Feldman, 1996). It follows that knowledge is considered to spread pervasively within the geographically delimited area, thus, being accessible to all actors located here. Secondly, it has been highlighted that the attention given to relations at the local and regional scales have led to a neglect of global linkages (Bunnell and Coe, 2001; Oinas and Malecki, 2002; Bathelt et al., 2004).

Recent contributions have specifically targeted these shortcomings, highlighting the need for assessing the effect of geographical proximity through the impact on the institutional setting and social networks. Thus, while geographical proximity *per se* has a limited effect on interactive knowledge creation, it significantly impacts the creation of shared norms, values and conventions, as well as social relations, thereby reducing the coordination costs associated with such collaborations (Storper, 1997; Singh, 2005; Breschi and Lissoni, 2009). It also follows from these insights that exclusion from local social networks prevents access to the local knowledge networks. Consequently, social relations to technological leaders (Giuliani, 2007) and gatekeepers (Morrison, 2008) are essential to benefit from the advantages of geographical agglomerations.

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[13] As an (over)simplification, the emphasis of the different theories are the following: the innovative milieu school stress relations between knowledge producing agents (and the milieu itself), contributions on the learning region focus on collaborations between partners with trust in each other, the industrial district literature highlights the role of collaboration between small and medium-sized enterprises, while the cluster theory puts a greater emphasis on competition and primarily relates collaboration to partners within the value chain and non-firm organisations.

The importance of social and cultural relations for interactive knowledge creation points to the possibility for distanciated collaborations, facilitated by social relations and shared conventions (Allen, 2000; Saxenian and Hsu, 2001). While it is argued that the importance of geographical proximity for knowledge creation increases over time (Sonn and Storper, 2008), other studies emphasise that geographically distant partners play crucial roles in knowledge creation processes (Amin and Cohendet, 2004; Bell and Zaheer, 2007; Fleming et al., 2007). Returning to Grabher (2002b; 2004), his notion of the project ecology draws attention to the balance between relations internal and external to the local area, in a way similar to a number of contemporary contributions (e.g. Bathelt et al., 2004; Doloreux, 2004; Wolfe and Gertler, 2004). While there is a clear focus on the benefits of geographical proximity for the projects in terms of e.g. shared conventions and the possibility for *"hanging out"* (Grabher, 202b, p. 254) in the agglomeration, the importance of distanciated relations building on personal networks is also acknowledged. However, the work of Grabher shares a weakness with most other approaches arguing for a mix of relations at different scales, namely that it lacks a coherent framework for analysing and understanding the importance of geography *vis-à-vis* other coordination mechanisms.

The theoretical conceptualisation of multiple proximity dimensions seeks to provide such a framework by moving away from a discussion of distance in purely physical terms. While rarely acknowledged in recent proximity literature, Lundvall (1992b) described at an early stage the possibility of substituting organisational proximity for geographical and cultural proximity. Generally, however, the origin of the proximity dimensions framework is ascribed to the work of French scholars from the *Proximity Dynamics group* which underline the distinction between geographical and organisational proximity (Kirat and Lung, 1999; Torre and Gilly, 2000; Torre and Rallett, 2005). In the work of Torre and Gilly (2000), *geographical proximity* refers to physical distance, influenced by the time and cost of transport as well as the perception of distance by individuals. *Organisational proximity* refers to relational distance, which affects the ability to coordinate action, as routines building on shared beliefs and tacit knowledge are constructed in organisations. Thus, it is illustrated that interactive knowledge creation and innovation processes are shaped by the relationship between social/relational aspects and geographical distance, and that the importance of these different proximities varies in different stages of learning processes. In this way, while maintaining an interest in geography, the outset is taken in the coordination process of relations.

While several proximity models have been developed (e.g. Blanc and Sierra, 1999; Kirat and Lung, 1999; Zeller, 2004), the model by Boschma (2005) gives the most detailed and thorough account of the relationship between proximity and innovation. Boschma's model contains five dimensions: geographical, cognitive, organisational, social and institutional proximity. *Geographical proximity* is defined as both absolute and relative distance, and the indirect impact on the other dimensions of proximity is stressed. *Cognitive proximity* is associated with differences and similarities in capabilities of economic agents. Differences in the cognitive capacities of actors can make it difficult to learn from each other as the ability to absorb the diffused knowledge is simply not available (Cohen and Levinthal, 1990). *Organisational proximity* refers to the extent of control of relations through intra- or inter-organisational arrangements. The degree of hierarchy has a great impact on the ability to coordinate economic activity and avoid uncertainty and opportunism. *Social proximity* refers to the strength of social ties between agents at the micro-level resulting from friendship, family relations or previous work related interactions. Again, this proximity influences the risk of opportunism, however, here through mechanisms of trust. Finally, *institutional proximity* describes the extent of shared norms, habits, rules and laws between economic agents. Thus, it depends on both the formal and informal *"humanly devised constraints that shape human interaction"* (North, 1992, p. 477).

A number of important discussions result from Boschma's work, some of which are explicitly considered in the papers of this thesis. Firstly, Boschma (2005) significantly questions the importance of geography for interactive knowledge creation. While Boschma notes that geographical proximity may facilitate other forms of proximity, he emphasises the possibility of substituting other forms of proximity for geographical proximity.[14] Consequently, compared to the territorial innovation models where the central role of geographical proximity is nearly unquestioned, it is much more uncertain in the proximity framework. Papers I and II deal with this issue.

Secondly, Boschma draws attention to the danger of too much proximity. On the one hand, each of the five types of proximity facilitates interaction and reduces coordination costs. On the other hand, too much proximity can lead to situations of lock-in due to a lack of openness. Therefore, the notion of the proximity paradox (Boschma and Frenken, 2010) emphasises that the partnerships with the lowest coordination costs may not be the most fruitful interactive learning processes, and that some distance is needed to stimulate collaboration. Empirically, this trade-off has been confirmed for cognitive and organisational proximity, while geographical and social proximity do not lead to less innovative collaborations (Broekel and Boschma, 2012).

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[14] Compare Boschma's (2005) emphasis with the contrasting focus of Malmberg and Maskell (2006).

Thirdly, and related to the former point, Boschma's framework raises the question of variation in proximity between cases. Empirical studies have focused on estimating the importance of different types of proximity in general (e.g. Ponds et al., 2007; Balland, 2012; Broekel and Boschma, 2012), while little attention has been given to the varying needs for different types of proximity, depending on the circumstances.[15] This issue is explored in paper II.

Summing up, Boschma's (2005) concept of proximity dimensions is centrally positioned in the theoretical framework of this thesis, as it provides a useful analytical tool to understand the role of geography relative to other dimensions of proximity. This is not to suggest that the framework is flawless and a silver bullet to the analysis of interactive knowledge creation; in some cases, it is challenging to disentangle one dimension from another, and it may open for misinterpretations to position the geographical dimension as independent from the other four.[16] Still, the framework is highly useful to understand and structure the analysis of interactive knowledge creation and innovation processes. Thus, rather than discarding the framework due to the flaws, the approach in this thesis is to address some of these challenges in the papers.

2.6. SUMMARY OF THEORETICAL FRAMEWORK

This chapter has introduced the general theoretical framework of the thesis. The two fundamental starting points are the increasing knowledge intensity of the economy and the understanding of economic development as an evolutionary process. While these foundations are perhaps given less explicit attention in the individual papers than the directly applicable conceptual frameworks, they are nevertheless the basic guidelines behind the overall research framing. The analysis of LMT industries emphasises the role of knowledge for these industries and the combination of traditional, inherited capabilities and external knowledge inputs, while the remaining papers focus on geographical proximity in interactive knowledge creation processes. In these analyses, the concepts of knowledge bases and proximity dimensions are central.

[15] A recent exception is Balland et al. (2011) who analyse the importance of different types of proximity depending on the position in industry life cycles.

[16] See also section 4.4 on future research directions.

3. Methods

Choices of methodologies are closely related to considerations concerning the philosophy of science. The scientific methods employed in this thesis are shaped by critical realism. This chapter initially outlines the central aspects of this perspective. Subsequently, the relation between critical realism and evolutionary approaches in economics and economic geography is considered. As explained in the previous chapter, the evolutionary perspective is part of the theoretical foundation of this thesis, and it is important to note the ontological assumptions of evolutionary theory and their correspondences with critical realism. It is argued in this chapter that critical realism and evolutionary theory have central characteristics in common at the ontological level, but also that a critical realist perspective may advance a purely evolutionary approach, in particular at the methodological level. Finally, the concrete research methods are presented with a focus on the relations to critical realism and evolutionary approaches.

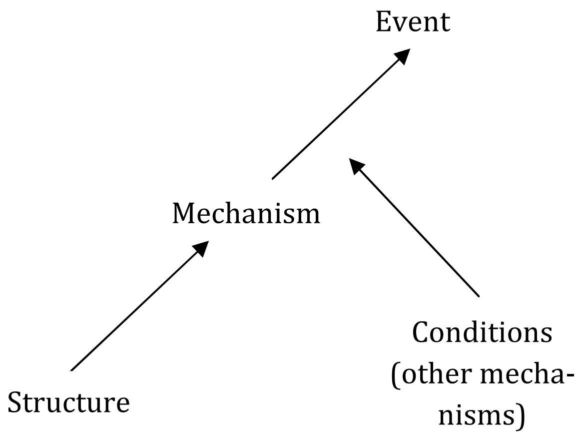
3.1. Critical realism

The critical realist philosophy of science is in particular associated with the work of Bhaskar (1978; 1986) and, within human geography, Sayer (1992; 2000). Critical realism has strongly contributed to philosophical developments at the ontological level. In accordance with traditional realist approaches, critical realism argues that reality exists independently of human consciousness and observations. Further, critical realism rejects simple empiricism understood as the reduction of the real world to the empirically observable (Sayer, 1981). Rather, the critical realist ontology differentiates between three domains of reality: the real, the actual and the empirical (Bhaskar, 1978; Danermark et al., 1997). Things exist in *the real domain* along with structures, mechanisms and causal powers which cannot be observed by humans. Events caused by these structures and mechanisms are part of *the actual domain*, regardless of whether they are observed by humans or not. Finally, observations made by humans fall within *the empirical domain*.

Science, in this differentiated ontology, is considered as studying phenomena at the empirical level and relating them to structures and mechanisms at the deeper levels. Scientific explanations of events provide theoretical descriptions of the mechanisms which caused the events (Foss, 1994; Lawson, 2001). This is at the core of research informed by critical realism. A further aim of science, from this perspective, is to understand and identify the variation over time and space of the mechanisms that result in these actual events (Lawson, 1997).

The process of analysing mechanisms relies on a thorough examination of objects and relationships between them (Sayer, 1981). Causal powers are assigned to both human reason and social structures. These mechanisms exist in themselves, independently of observation, and both over- and under-socialised conceptualisations of reality are rejected by critical realists. Events are considered context dependent rather than determined by structures; the effects of structures vary according to specific conditions (see figure 3). The attention given to time and place specific factors in the analysis of causal mechanisms is perhaps a main reason explaining the popularity of critical realism in human geography.

Figure 3. Critical realist view of causation



Source: Sayer (2000; p. 15)

Epistemologically, critical realism rejects both totalism and relativism. Critical realists deny the existence of a fully developed observation language which allows perfect communication of empirical observations, but maintain at the same time that observations are not completely subjective and depending on theoretical point of departure (Sayer, 1981). In the phrasing of Yeung (1997, p. 54), *"all knowledge is fallible, but not* equally *fallible"*, and it is through a constant critique that the sources of errors are identified.

Critical realism does not clearly specify a particular methodology but places the responsibility for this task with the scientific communities in the different disciplines of social science. It is argued that this part is underdeveloped within economic geography (Yeung, 1997; 2003). Writing from a position within economics, Lawson (1997) suggests that the search for demi-regularities (in short: demi-regs), defined as partial event regularities, are important in the initial research phase. As these demi-regs are acknowledged to be, by definition, non-universal, one cannot formulate theoretical descriptions of the mechanisms causing the events solely on this basis. Still, they provide indications of general patterns that point to interesting research topics. When expectations (compared to previous or peer group performance) concerning a particular phenomenon are repeatedly not met, demi-regs point to a mechanism previously unknown or neglected.

Most often, such demi-regs are detected through the use of quantitative methods which can establish empirical regularities between objects. These non-causal mechanisms can inform abstraction of causal mechanisms (at the real domain) which can potentially account for the phenomenon under investigation, but qualitative methods are needed to understand such causalities (Yeung, 1997; Lawson, 1997). The process of abstraction can be considered an instrument to identify the relevant dimensions of a research object in a given situation. As social science topics are always concerned with the functioning of open systems, it is necessary to disregard irrelevant relations and focus on the aspects and their relationships that are central to understanding mechanisms (Sayer, 1981; 1992; Lawson, 1997).

The danger of trying to isolate causal mechanisms in this way is that it becomes difficult to understand the *wholes* in which critical realism is interested The suggested solution is to combine insights from multiple abstractions into a synthesised understanding (Lawson, 1997). Thus, several abstractions are often needed to uncover causal mechanisms. Further, Yeung (1997) suggests that once the mechanisms have been formulated they should be re-examined empirically and if necessary revised. In this way, the research process proceeds in a number of iterations that continuously shift between the abstract and the concrete.

A further key methodological question concerns the characteristics of suitable abstractions. It is a research project in itself to analyse this problem, but as noted by Lawson (1997), abstractions are often pushed too far, e.g. in mainstream economics, which generally ignores the contextual influence on economic structures. Yeung (1997, p. 60) provides a number of abstraction criteria and emphasises the importance of analogies in informing abstractions. Thus, insights from, e.g. evolutionary biology can inform critical realist research within the social sciences.

3.2. Critical realist and evolutionary ontologies

It has been noted recently by authors from the field of economics that the evolutionary and critical realist ontologies are closely related and share several critical features (Foss, 1994; Northover, 1999; Castellacci, 2006). Castellacci (2006) emphasises complexity, the transformational model of social action, continuous change in open systems, and pervasive uncertainty.

Firstly, the two perspectives share a view of reality as complex, differentiated and structured. In the evolutionary framework, variation is a fundamental characteristic. The composition of the population is continually moulded through complex learning and innovation processes, building on interactions between actors (Foss, 1994). A systemic perspective is needed to understand the structuring of these interrelations (Nelson, 1993). This view is closely linked to the critical realist emphasis on analysis of causal mechanisms at a deeper level (Castellacci, 2006). In the critical realist view, positions in society are internally related and single actions are influenced by and influence others (Lawson, 1997; 2001).

Secondly, critical realism argue for a transformational model of social action, understood as pre-existence of social structures that influence individual action, but which are also reproduced and transformed by it. Both Northover (1999) and Castellacci (2006) note that evolutionary economists adopt a similar social model more or less implicitly: in evolutionary economics, individuals make choices under the influence of social structures, but thereby also contribute to changing the institutional environment. However, there seems to be some differences between the positions of central evolutionary economists and economic geographers on the important and related question of *what constitutes the selection environment?* On the one hand, Nelson (1995) argues that, while firms have a great influence on their own selection environment, all kinds of other organisations and institutions do as well. Further, he stresses that the development of economic institutions depends on a diverse set of mechanisms, and that there is little reason to believe that economic efficiency guides the selection environment. Along similar lines, Hodgson (2006; 2009) considers that intentionality is as much a consequence as a cause, since institutions can change – and not just enable or constrain – behaviour. Institutions can have downward causation, thus, a dual emphasis on agency and institutional structure is necessary.

On the other hand, Boschma and colleagues fundamentally restrict the influence of institutions to exactly enabling and constraining (Boschma and Frenken, 2006; 2011). In their view, institutions are considered *explananda* on line with, e.g. locational behaviour of firms and territorial development – the *explanans* are the variations in routines between territories and the resulting differences in firm behaviour. Thus, they focus on how actors can create and change institutions (Boschma and Frenken, 2009; Strambach, 2010). Overall, the importance of routines for the fitness of firms appears to be even greater in evolutionary economic geography than in evolutionary economics. This position has been criticised for an overemphasis on micro-scale actors and a theoretical relegation of institutions (MacKinnon et al., 2009; Pike et al., 2009; Coe, 2011), which are features that are incompatible with a critical realist ontology.

Thirdly, both critical realism and evolutionary economics apply an open system view associated with continuous change and transformation (Castellacci, 2006). The work of Lawson (1997; 2001) emphasises continuous reproduction and transformation as well as the importance of time-specific analyses of causal mechanisms – *"the future is open"* (Sayer, 2000, p. 15). Naturally, this perspective is in accordance with evolutionary economics, where innovation and search for improvements are key mechanisms. Transformation is considered to result from both radical and incremental innovations and the speed of change is highly variable (Nelson, 1995).

Finally, critical realism and evolutionary economics share a view of the world as characterised by strong and pervasive uncertainty, where the effects of mechanisms change over time (Northover, 1999; Castellacci, 2006). In the evolutionary framework, this is expressed as the non-constant character of the selection environment, due to the impossibility of predicting the development of technological change. The coexistence of inertial forces and constantly renewed variation implies that evolutionary scholars concurrently focus on issues of path dependence and path destruction (Glückler, 2007).

Summing up, there are great ontological overlaps between critical realism and evolutionary economics. However, these similarities have not resulted in convergence of methods.

3.3. Critical realist and evolutionary methodologies

As discussed in the previous section, Castellacci (2006), among others, convincingly argues that critical realism and evolutionary economics share critical ontological features. He continues by arguing – less convincingly – that they also share central methodological characteristics due to the shared aim of analysing evolutionary and causal mechanisms at a deep level, rather than merely studying superficial empirical evidence. However, it appears that the methodological overlaps identified by Castellacci (2006) reflect similarities that could or ought to be, rather than actual existing similarities. Due to the ontological foundations, critical realism and evolutionary economics share the view of a need for abstraction or appreciative theory, which Nelson (1994, p. 292) describes as *"an abstract body of reasoning"*, where some variables and relationships are ignored. Nevertheless, the methods of reaching an understanding of the causal mechanisms are very different.

Methodologically, evolutionary economics distances itself from neoclassical economics where empirical work is generally considered detached from theorising. In their work, Nelson and Winter (1982) seek to combine *appreciative theorising* based on the evolutionary ontology and its mechanisms, with *formal theorising* in the form of modelling of evolutionary economic processes. Thus, while the evolutionary methodology prescribes different assumptions than neoclassical economics due to ontological considerations, the emphasis on formal modelling and econometrics is maintained. A very similar methodology is advocated in evolutionary economic geography. With reference to Nelson and Winter, Boschma and Frenken (2006, p. 292) argue for a *"methodological pluralism"*, which, in their view, implies both formal modelling and case study approaches. While qualitative approaches are not rejected, they are clearly not considered central to evolutionary economic geography (see also Boschma and Martin, 2010).

Thus, evolutionary economics and evolutionary economic geography maintain a strictly quantitative focus, where few studies use quantitative analysis in the way prescribed by Lawson (1997), i.e. as a method for identifying interesting demi-regs that can point to causal mechanisms, which are subsequently explored in detail through qualitative studies (see also below, section 3.4). While critical realism is, as noted above, generally not very elaborated on the methodological part, it is still clear that qualitative theories are considered necessary to uncover causal mechanisms (Yeung, 1997). Sayer (2000) puts it even more boldly by stating that gathering data on repeated occurrences says nothing about the causes of events. In this way, a critical realist approach draws attention to the value of using qualitative approaches within an evolutionary framework. Further, following Sayer's (2000) perspective does in fact challenge the understanding of the evolutionary ontology as deep. While it may have depth *de jure*, the overemphasis on quantitative studies may lead to a *de facto* shallow ontology due to the inability to thoroughly examine causal mechanisms.

3.4. Research design

Based on these ontological and methodological considerations, the research design of the thesis is presented in this section. As the thesis aims to analyse both the geographical and sectoral organisation of the knowledge economy, the following two subsections deal with the research designs related to A1 and A2, respectively. In both cases, a mix of quantitative and qualitative methods is applied in accordance with the methodological guidelines outlined above.

3.4.1. Research design – geographical organisation

The aim of the research carried out in this part of the thesis is to study the impact of geographical proximity on interactive knowledge creation. The outset is a critique of existing work within this field which has been criticised for overemphasising the benefits of geographical proximity (Bunnell and Coe, 2001). While research on non-local interactive knowledge creation has been increasing over the last decade, there is still a lack of a detailed understanding of the causal mechanisms explaining the actions of organisations in these situations – even within evolutionary economic geography, which stresses the importance of organisational routines. The relation between geography and other forms of proximity is unclear, and variation along the proximity dimensions in interactive innovation projects is not understood.

Having noticed the inadequacies of the current understanding of the impact of geography on interactive knowledge creation, it can be concluded that there is a need for further developing the theorisation of the causal mechanisms. Paper II is in particular concerned with this issue. Based on a literature review, it is argued that incorporating perspectives from organisational theory can assist in understanding these relations and their geographical characteristics. The fundamental argument is that, subject to structural constrains, the objectives of the partnerships contain causal power concerning the resulting proximity characteristics of the partnerships.

The actual research methodology proceeds in three phases, examined in papers I, II and III. Paper I examines the relations between, on the one hand, geography and, on the other hand, institutional, social, cognitive and organisational proximity in interactive knowledge creation. Data on distance, according to the different proximity dimensions between partners in 180 collaborative product development projects, has been gathered through 50 structured interviews with firm representatives. Schoenberger (1991) notes that control can be an issue in interviews with business leaders as they are used to exercise authority over others, and the structured interview technique was therefore chosen to ensure that useful responses were provided to a number of key questions[17]. The analysis offers an examination of proximity relations in the actual domain through the use of ordered logit models. This is complemented by a qualitative analysis that gives specific attention to the relationship between two of the proximity dimensions. However, a detailed qualitative analysis is needed to understand the deeper causal mechanisms behind these relations and the variation in proximity between partnerships. Paper II presents such an analysis.

Paper II uses the same empirical data as paper I, but analyses it in a very different way. The qualitative approach makes it possible to draw conclusions concerning causal mechanisms to a much greater extent than the quantitative analyses. The analytical process has progressed in the following way: the author of the thesis has carried out all 50 interviews which were all audiotaped. The interview material was processed right after each interview. Upon completion of data collection, observations were sorted according to the conceptual framework adopted from organisational theory, which differentiates seven objectives underlying technology cooperation between firms (Hagedoorn, 1993). A detailed transversal analysis along these categories was performed, which led to a modification of the framework, reducing the number of categories from seven to five. Finally, the analysis is structured according to these five categories and it includes a considerable number of quotes from the interviews. This process illustrates the continuing shifts between the abstract and the concrete that characterises the critical realist research process, and which here leads to an empirical validation of the role of objectives as a significant factor influencing the resulting characteristics of the partnerships according to the proximity dimensions.

Paper III is a quantitative analysis of the impact of changing geographical distance[18] over time on interactive knowledge creation. The analysis takes advan-

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[17] Structured interviews do not prevent the use of open-ended questions, which were also applied in this case; see the following description of paper II.

[18] Here understood as functional distance, i.e. physical distance influenced by the time and cost of transportation.

tage of the opportunity for a 'natural experiment' created by the construction of a fixed link connecting Denmark and Sweden in 2000, by examining the quantity and character of research collaborations between the Danish and Swedish parts of the cross-border Øresund Region from 1994 to 2009. In the analysis, the number of co-authorships is considered as a representation of the extent of research collaboration. Data is obtained from the Science Citation Index Expanded database available through ISI Web of Knowledge. In order to assess whether the development in research collaboration between the two parts of the region is atypical or part of a general trend, data is obtained on the number of co-authorships between the Øresund Region and five other city regions[19]. While this analysis does not provide a detailed understanding of causal mechanisms, it leads to an identification of interesting demi-regs concerning the relation between changes in functional distance and collaboration patterns, which point to an interesting future area of research.

3.4.2. Research design – sectoral organisation

The aim of the second part of the thesis is to investigate the development of LMT manufacturing industries in high-wage countries. The point of departure for this work is a critical view on current research and public policy which give overwhelming attention to the development of high-tech industries. Contrary to this widespread assumption, the initial parts of papers IV and V demonstrate quantitatively that LMT manufacturing industries continue to be of great economic importance for high-wage countries and that no significant changes of the manufacturing sector's overall composition has taken place. Paper IV draws on employment and value added data on 12 European countries[20] from the OECD's STAN database over the period 1995 to 2006. Paper V uses Danish data on the same variables from Statistics Denmark's RAS and NAT databases in the periods 1999 to 2008 (employment) and 1990 to 2006 (value added).

These quantitative findings provide the demi-regs which inspire and inform the subsequent deeper analysis. In essence, the additional contributions in papers IV, V and VI examine the causes of the continuing importance of LMT industries in high-wage countries, with each paper focusing on a specific aspect, thus, abstracting from other relations. Combining the insights of the three papers provides a synthesised understanding of the position of LMT manufacturing industries in the contemporary knowledge economy that highlights both *path continuity* rooted in

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[19] Basel, Massachusetts, New Jersey/New York, Île-de-France and Stockholm.

[20] Austria, Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Portugal, Spain, Sweden and the UK.

traditional, inherited capabilities and *path moulding*[21] based on external knowledge inputs.

The focus of paper IV is on the interconnectedness of high- and low-tech industries. The analysis draws on 25 interviews with British and Danish business managers from firms in the fabricated metal and plastics industries, as well as six interviews with representatives from industrial organizations in these industries. The two industries were chosen because they are among the most important non-research-intensive industries in Europe, in terms of both employment and value added. Further, interviews were carried out in two countries in order to reduce the risk of capturing nation-specific trends. In both countries, the selected firms are located neither in large cities nor in the most peripheral parts: the British firms are located in the West Midlands and Yorkshire, in the area between Birmingham and Leeds, the Danish firms in the region around the fourth-largest city in Denmark, Aalborg. In both cases, the selected industries are of considerable economic importance for the regions. The interviews were processed similarly to the interviews in paper III, and the analysis of the relations between high- and low-tech industries is structured according to the two main themes appearing from the material.

Paper V examines innovation strategies in LMT industries through 20 interviews with representatives from firms, educational institutions and industrial organisations from the fabricated metal industry. There is a partial overlap between the empirical material of papers IV and V, thus, paper V is also focused on the region around Aalborg. The point of departure for this paper is previous theoretical work on LMT innovation processes (Hirsch-Kreinsen, 2008). While the analysis highlights the appropriateness of this framework, it also draws attention to other factors, e.g. the importance of strategic capital goods investments, which need to be considered in further theorisation.

Finally, paper VI analyses the importance of human capital in LMT industries over time. The paper is a quantitative analysis based on employment data from Statistics Denmark's RAS database over the period 1993 to 2006. Distinguishing between industries according to R&D intensity, the development in the share of highly-skilled employees is examined over time. In the paper, human capital in the form of highly skilled labour is measured as the share of employees with formal education equalling bachelor's degree, master's degree and PhDs, equivalent to ISCED categories 5A and 6 (UNESCO, 1997). Similar to the other quantitative

[21] Rather than the "standard" evolutionary economic geography term of *path creation* (e.g. Martin and Sunley, 2010), the term *path moulding* is preferred here as it signifies a less radical change of direction, which is better suited to the current case.

papers in this thesis, paper VI does not provide an understanding of causal mechanisms by itself, but it does assess the importance of human capital in LMT industries and the geographical divides of this development. Further, similarly to papers IV and V, it gives a nuanced understanding of the position of LMT industries in the knowledge economy.

3.5. SUMMARY

In summary, this chapter has presented critical realism and its relation with evolutionary approaches to economics and economic geography. Further, the research design of the thesis has been described with particular attention to the foundations in critical realism and evolutionary approaches. The research in the papers is based on continuous shifts between the abstract and the concrete, as well as between quantitative and qualitative methodologies. By applying this research design, the thesis seeks to enhance the understanding of the geographical and sectoral organisation of the knowledge economy.

4. Findings and conclusions

This chapter summarises the findings of the six papers and presents the overall conclusions of the thesis based on these. Summaries of the findings in each of the papers are given in section 4.1. Conclusions and answers to the research questions are provided in section 4.2. Additionally, the relation between the two parts of the thesis is discussed and some directions for future research are outlined. No specific policy section is included – papers III, IV, V and VI are all explicitly concerned with policy issues, and the main policy recommendations are reported below in the summaries of the individual papers.

4.1. Summary of findings

The starting point of **paper I** is an interest in the importance of geographical proximity for collaborative innovation projects. On the one hand, some scholars emphasise that geographical proximity has a positive impact on developing other forms of proximity. On the other hand, others highlight that these forms of proximity (e.g. social proximity) are at least as important for partnership formation as geographical proximity. Thus, while the first position focuses on the *overlap mechanism*, where geographical proximity facilitates other forms of proximity, the second position stresses the *substitution mechanism*, where these forms of proximity substitute for geographical proximity. The paper applies the proximity framework of Boschma (2005) in an empirical analysis of the importance of these two mechanisms in product development projects in the Danish cleantech industry. Data on 180 partnerships has been collected through interviews with representatives from cleantech firms. Four ordered logit models analyse the relations between geography and the institutional, social, cognitive and organisational dimensions of proximity. The results indicate that the relation between the geographical and social dimensions is influenced by both the substitution and overlap mechanisms, while only a substitution effect is found concerning the organisational and cognitive dimensions. Finally, the regression analysis highlights that while the geographical and institutional dimensions overlap, there is no indication of a substitution effect in this relation. This issue is dealt with in detail through a qualitative analysis, which highlights that there is indeed a substitution effect between institutional and geographical proximity. However, these instances are few and far between, and social proximity is an essential intermediate in these cases. Thus, similarly to the suggestion by Gertler (2003), the analysis emphasises that institutional differences are the main challenges for long-distance collaborations.

Paper II is based on the same empirical material as paper I, and it also applies Boschma's (2005) multi-dimensional proximity framework. This paper goes beyond previous contributions analysing partnership characteristics along multiple dimensions of proximity. Rather than analyzing whether the different proximity dimensions facilitate partnership formation or not, the paper is concerned with variation in proximity between different partnerships. Drawing on organisational theory on partnership formation, the paper emphasises how collaboration objectives are a key factor explaining this variation. A qualitative analysis of data on collaborations in the Danish cleantech industry highlights how collaboration motives lead to differences in selection criteria. Firms seek partners with different characteristics depending on whether they seek to assess complementary technologies, influence market structure, obtain knowledge, reduce the innovation time-span, or share costs and risks. Thus, rather than searching for an optimal level of proximity, the analysis emphasises the importance of recognising the heterogeneity of the partnerships, the reasons for this variation, and the value of having access to a diverse portfolio of potential partners. Further, the paper increases the understanding of when geographical proximity matters for collaborative product development processes. The analysis highlights that long-distance relations play a minor role in collaborations at the core of innovation processes, which aim at assessing complementary technologies, obtaining knowledge or reducing innovation time-span. Thus, while global pipelines appear to be important for collaborations motivated by market access and cost considerations, the conclusions of the paper warn against understating the importance of geographical proximity for collaborations between actors, particularly those directly related to innovation processes.

Paper III is concerned with the relation between changes in geographical proximity and collaboration patterns. Further, the paper contributes to the literature on cross-border innovation by addressing the effect of the construction of the fixed link between Denmark and Sweden on collaboration patterns in the Øresund Region. With a focus on research collaborations, the object of analysis is co-authorships between the Danish and Swedish parts of the Øresund Region, with a particular emphasis on the field of biotech. The analysis is based on data from Science Citation Index Expanded on the number of both total and biotech co-authorships for each year in the period 1994-2009. Citations are recorded for the biotech co-authorships as a proxy for research quality. In addition to collaborations between actors from the Danish and Swedish sides of the region, the developments in co-authorships between the Øresund Region and five city regions with significant concentrations of biotech industry are included in the analysis. The results indicate that the increasing geographical proximity does not in itself lead to a higher level of integration and cross-border research collaboration, as the growth in co-authorships between the two parts of the Øresund Region is relatively low over the period compared to the development in collaboration with the other major research hubs. However, high growth rates concerning both the quantity and quality of Danish-Swedish co-authorships are found within the biotech sector, where a targeted policy effort has been made to strengthen the cross-border network. These findings indicate that designated cross-border policies that strengthen social proximity make it possible to exploit the possibilities offered by the geographical proximity resulting from infrastructural investments.

Turning to the papers dealing with the thesis' second aim – to investigate the development of LMT manufacturing industries in high-wage countries – the outset of **paper IV** is taken in the policy focus of the EU on R&D as a driver of economic growth. The arguments in favour of such a policy are examined, and it is concluded that there is little empirical evidence supporting them: EU GDP growth is not underperforming compared to the more R&D intensive US economy, and LMT industries, characterised by limited R&D investments, are not less able to withstand competition from low-wage countries compared to high-tech industries. With paper V dealing with specific LMT innovation strategies, paper IV focuses on the interconnectedness of low- and high-tech industries as an additional important factor explaining the continuing competitiveness of LMT firms in high-wage countries. Based on interviews with Danish and British firms and organisations from the fabricated metal and plastics industries, the analysis highlights, firstly, that LMT firms are important customers to the products of high-tech firms, and secondly, that LMT firms play an important role as partners in the innovation processes of high-tech firms, contributing with knowledge on materials and engineering techniques. Further, geographical proximity appears to be of significant importance for these collaborative innovation processes, thus, the analysis underlines the benefits of a diverse industrial composition. Finally, it is argued in the discussion that the EU policy focus on R&D intensifies inter-regional inequality in Europe. Prioritising high-tech industries is associated with an increasing focus on the regions where these industries are concentrated, that is large, prosperous city regions. In this way, the policy agenda gives insufficient attention to the heterogeneity of European regions.

Similarly to paper IV, **paper V** takes the outset in the discrepancy between the emphasis on R&D-focused policies and the continuing economic importance of LMT industries. However, in this case, the focus is on Denmark rather than the EU. Examining the fabricated metal industry – a medium low-tech industry that has achieved significant increases in labour productivity in recent decades – the paper analyses the characteristics of innovation processes in this industry. Based on interviews with representatives from Danish fabricated metal firms, the paper confirms the importance of innovation strategies focusing on incremental improvements of products and production processes, and – in particular – the ability to create tailor-made solutions. The resulting close relations with customers imply that competition from low-wage countries is of limited importance for most of these firms: the development of customised products requires frequent face-to-face interaction which is too costly over long distances. These findings have implications for public policy, which in a Danish context is inadequate for supporting incremental innovations and collaborations between producers and customers. Thus, it is argued that public policy should reflect the specificities of LMT innovation processes, and adopt a more inclusive innovation policy

The importance of competences and skills is emphasised in both papers IV and V. **Paper VI** deals with a closely related topic, namely the role of human capital in LMT industries. The importance of highly skilled labour for economic development has been thoroughly studied for high-tech industries, and human capital is often considered particularly important for these industries by academics and policymakers. This paper analyses the use of human capital over time in low-tech industries, compared to industries with higher R&D intensity. Based on Danish employment data covering the period 1993-2006, the analysis highlights that human capital appears to be equally important for economic development in low-tech industries; in fact the share of highly skilled labour has a significantly lower growth rate in the three other types of industries. Additionally, the paper draws attention to the importance of geography: there is a clear urban/rural divide in the localisation of highly skilled labour within all types of manufacturing industries favouring municipalities in and around Copenhagen. Further, this divide is becoming more pronounced over time, thus, urbanisation economies play the primary role in explaining the geography of human capital rather than the localisation of high-tech industries. These findings imply, firstly, that policies aimed at attraction and retention of highly skilled labour should not specifically target high-tech industries, but rather have a broader focus. Secondly, while low-tech firms in urban areas are restructuring and significantly increasing the proportion of highly skilled labour, this is only the case to a lesser extent in peripheral regions. One can fear that this can have negative implications for the future viability of low-tech manufacturing activities in peripheral locations.

4.2. Conclusions

The main conclusion of the first three papers of the thesis is that geographical proximity has a significant impact on interactive knowledge creation; however, the effect of geography cannot be isolated from other forms of proximity. Thus, it is crucial to understand the relations between, on the one hand, geography and, on the other hand, institutional, social, cognitive and organisational proximity dimensions. Such a perspective highlights that the positive consequences of geographical proximity is closely related to its facilitating effect on institutional and social proximity. This is not to suggest that geographical proximity is indispensable to interactive innovation projects. Social, cognitive and organisational proximity may substitute for geographical proximity in such projects. Distanciated collaborations are significantly more likely between actors with established social relationships, shared knowledge bases or common ownership. Hence, to understand the connections between geography and the four other proximity dimensions, it is necessary to simultaneously account for the degree of overlap and substitution in these relations.

The insight that collaborations are characterised by very different degrees of proximity along the different proximity dimensions, raises the question of how this variation can be explained. Without disregarding the influence of contextual factors on the variation in partnerships' characteristics, it is argued here that differences in collaboration objectives have a crucial influence on the resulting partnerships. This can be illustrated by comparing collaborations with the purpose of assessing complementary technologies with those focusing on reducing innovation time-span. In the case of the former, firms look for partners with knowledge within a different domain, thus, with low cognitive proximity. On the contrary, high cognitive proximity is a necessity in the latter type, which does not allow time for overcoming large cognitive differences. This time pressure also implies that firms often have to settle with unknown partners even though they prefer well-known collaborators. Conversely, social proximity is crucial to make up for the low cognitive proximity in the former type of collaborations. In both cases, though, firms prefer partners located in geographical proximity due to the need for frequent interaction and high institutional proximity. However, this is not the case for collaborations driven by market access or cost considerations; thus, the role of geographical proximity also varies depending on collaboration motives.

Considering the effect of geographical proximity on interactive knowledge creation, it can be expected that changing geographical proximity alters collaboration patterns. However, this effect is not immediate or automatic. Improved accessibility is, to some extent, valuable on its own, but a sudden increase in geographical proximity is not associated with corresponding intensification of institutional and social proximity. While geographical proximity facilitates these forms of proximity, it does so over time. Hence, there is a temporal dimension to the impact of changing geographical proximity on collaboration patterns. Changing geographical proximity does not modify institutional and social proximity from day one, but only in the long run through improved possibilities for encounters and the development of shared institutions. Alternatively, efforts designated at stimulating, e.g. social proximity, may accompany investments in increasing geographical proximity, and enhance the short-term effect on interactive knowledge creation.

Together, these conclusions emphasise the value of an analytical perspective on the relation between geography and collaboration that goes beyond the simple dichotomy of localised and non-localised collaborations (found in e.g. Doloreux, 2004). Embarking on a discussion of 'staying local' or 'going global' is bound to be unfruitful, if the nature of relations being considered is unspecified, or if it is not founded on an understanding of the consequences of both geographical proximity and distance. This holds true for scholars and policymakers alike. Public policy is a key factor shaping collaboration patterns between actors, but one can be concerned that such policies are often, firstly, founded on insufficient knowledge concerning the role of geography, and, secondly, inadequately considering the differences of various types of relations. Thus, while it is certainly unrealistic to envision that policies can always take the context fully into account – i.e. considering the relevant types of relations, the role of geography for these relations, and how these factors change over time – policymakers should ideally be aware of the different mechanisms that policy schemes may initiate, and the resulting implications for collaborative knowledge creation and innovation processes.

In terms of research, the conclusion of the thesis echoes the suggestion of Bunnell and Coe (2001, p. 583) that *"the way forward is not merely to posit a need for multi-scalar approaches, but rather to explore interconnections and interrelations between and across scales."* Adding to this quote, the papers suggest that the way forward is also to examine the characteristics of these interconnections and interrelations. In fact, it is exactly by leaving behind the narrow focus on geography, and replacing it with an approach sensitive to social, institutional, cognitive and organisational relations, that the importance of geography for economic development becomes evident. This requires openness among economic geographers to draw on insights from other social science disciplines including sociology, economics, psychology, organisational and management studies, and political science. This need does by no means reflect a lack of adequate theorising in economic geography, but is rather a fundamental condition of the discipline, which is at times overlooked. As noted by Asheim (2006), Immanuel Kant classified geography and history as the two physically defined sciences, while other disciplines such as sociology and economics are defined by their respective objects of study. Thus, as an empirical based science, geography must necessarily maintain close links with a number of relevant logically defined sciences. This is perhaps more important than ever, due to the unprecedented complexity of economic relations in the contemporary knowledge economy. The increasingly diverse amount of cross-cultural relations, the growing plurality of organisational forms, and intensifying specialisation of competences imply that understanding the geography of interrelations necessitates a constant engagement with other disciplines.

Moving on to the second part of the thesis, the main conclusion of these three papers is that LMT industries maintain significant economic importance in high-wage countries, but the character and activities of these industries are profoundly changing. Contrary to the assumptions of much academic and policy work, LMT manufacturing industries continue to be highly present in Western countries. While the shares of manufacturing employment and value added constituted by low-tech industries have decreased slightly over the recent decades, this is not the case for medium low-tech industries. Consequently, the two categories continue to make up the clear majority of both manufacturing employment and value added in Europe. Further, there are not considerable differences between the developments in labour productivity of the different types of industries since the millennium. Thus, in summary, the economic performance of LMT manufacturing industries in high-wage countries is comparable to the more R&D intensive industries.

The papers highlight that LMT firms are not passively waiting to be outcompeted by firms from low-cost countries. Instead, they are actively pursuing strategies to maintain competitiveness and increase the value added of products and processes. The innovation strategies of LMT firms are founded on inherited capabilities that provide a platform for incremental improvements of products and production processes as well as the customisation of products. A strong synthetic knowledge base allows firms to, e.g. change from producing large batches of standardised products to specialising in prototype fabrication. Associated with the increasing emphasis on such higher value added activities is frequent collaboration with high-tech firms. Again, a strong synthetic knowledge base is a prerequisite for entering such collaborations, as high-tech firms are often specifically interested in partners with a thorough knowledge of materials and production processes. Besides from the direct benefits of participating in such projects, they also allow LMT firms to access analytical knowledge that is otherwise difficult to acquire.

In this way, while LMT industries may – by definition – have low R&D investment levels, they nevertheless maintain competitiveness through other measures. However, it must be noticed that these developments rest on investments of other types – in human capital and capital goods. The thesis does not explicitly consider capital investments, but preliminary results of an analysis of development in capital investments over time in Danish manufacturing suggest that the capital intensity of low-tech industries increases significantly compared to other types of industries, particularly concerning investments in machinery (Hansen and Winther, 2012). Concerning the importance of human capital, highly skilled labour is of increasing importance for low-tech firms, allowing them to innovate in alternative ways and collaborate with high-tech firms.

A synthesis of these conclusions underlines that LMT firms are in general not particularly threatened by increasing global price competition. Of course, some LMT firms will maintain a focus on cost competition, and not intensify investments in skills and equipment. While the future viability of these firms is highly uncertain, most LMT firms use a variety of means to stay competitive. Thus, framing the conclusion in a positive tone, there is clearly significant potential in advancing the position of LMT industries in high-wage countries, which policymakers should pay attention to. In fact, following the argument of Porter (1990), a selective factor disadvantage concerning wages can stimulate a quick transition towards innovative practices that may secure a long term strong position of Western European LMT industries.

However, the changing character of LMT manufacturing is also resulting in some worrying prospects. Firstly, the position of unskilled labour in an increasingly advanced manufacturing industry is of particular concern. Traditionally, LMT industries have been major employers of unskilled labour, but the increasing sophistication of products and production processes, and the accelerating substitution of machinery for labour imply that this is gradually less the case. As argued by Christopherson and Clark (2007), while not all industries have a great need for employees with PhD degrees, medium-skilled labour is increasingly becoming a minimum requirement across different types of industries. In this way, the developments that underpin the continuing competitiveness of Western European LMT firms are associated with an increasing employment problem for unskilled labour.

Secondly, the concentration of LMT manufacturing has traditionally been high in peripheral regions, but this may change in the future. In short, there might be a spatial dimension to the changing character of LMT manufacturing. While this proposition is tentative and open for debate, some supporting indications can be found in the papers. First and foremost, the increasing spatial concentration of highly skilled labour for low-tech industries, in and around urban areas and in particular Copenhagen, is notable. Even though this is not surprising *per se*, as highly skilled labour is generally concentrated in urban regions, it is nevertheless a worrying outlook for peripheral areas, if it is accepted that an upgrading of the qualifications of the workforce is a central aspect of a future competitive LMT industry. Thus, without entering the discussion of people moving for jobs or jobs moving for people (see e.g. Storper and Scott, 2009), this development will, *ceteris paribus*, increase the incentives for LMT firms to locate in urban areas. Further strengthening this effect is the importance of collaborations with high-tech firms. As these collaborations appear to be particularly sensitive to geographical distance, due to significant cognitive differences, such partnerships represent another incentive for LMT firms to locate in urban areas, which are the predominant locations for high-tech industries. However, the continuing importance of traditional capabilities is likely to moderate this tendency, as they are not necessarily available in other locations and difficult to transfer over space. Still, in the long run, it is questionable whether this reason will be sufficiently important to prevent a locational shift of LMT industries towards urban locations.

Based on this analysis of LMT industries, a final question to consider is the relevance of the low-tech/high-tech taxonomy. Certainly, the R&D intensity of industries is an important characteristic, but the emphasis in policymaking on high-tech industries suggests that this taxonomy does more harm than good. There is a need for a broader conception of manufacturing in the knowledge economy, which goes beyond R&D and radical innovations. Thus, more nuanced taxonomies (e.g. Pavitt, 1984; Bar-El and Felsenstein, 1989; Laestadius et al., 2005) that pay attention to, among other things, human capital levels and capital investments have more to offer. Additionally, there is a need to understand the position of industries in geographical space, paying special attention to features such as the interconnectedness of different types of industries and access to skilled labour. While the institutionalisation of the low-tech/high-tech taxonomy in policy circles makes it unlikely that it will be abandoned any time soon, one of the results of this thesis is to emphasise that there is an alternative to this narrow understanding of the knowledge economy.

4.3. Linking the geographical and sectoral perspectives

As it is evident from figure 1, in this thesis, innovation and knowledge creation processes are considered central to understanding the geographical and sectoral organisation of the knowledge economy. The topic is approached from two different angles, with the first part examining the role of geographical proximity on interactive knowledge creation, and the second part analysing the development of LMT manufacturing industries in high-wage countries. While these perspectives are distinct, there are nevertheless important linkages between the two parts. This section will reflect upon three of these that exemplify how the conclusions from one part have implications for the other, and underline the complementarity of the perspectives on the role of innovation in the knowledge economy.

Firstly, a main topic in the first part of the thesis is the influence of collaboration objectives on the degree of proximity in partnerships. One finding of paper II is that collaborations with the motive of assessing complementary technologies are characterised by a low cognitive proximity, which, again, necessitates high geographical proximity in order to reduce coordination costs. This finding is replicated in the analysis of the relations between high- and low-tech firms in paper IV, where the importance of physical proximity is emphasised due to the differences in knowledge bases between the partners. While conclusions from studies of the cleantech sector, which is characterised by a great heterogeneity concerning the research intensity of firms, should not be uncritically transferred to the LMT industry, this nevertheless exemplifies the relevance of the findings in the first part of the thesis for understanding the development of LMT industries.

Secondly, the papers within the two parts complement each other concerning the link between customer relations and innovation processes. On the one hand, the LMT analysis underlines the importance of customer relations for innovation processes. It is stressed in paper V that the customisation strategy is of central importance for the competitiveness of LMT firms, and that innovative solutions are often reached through close collaboration with customers. Thus, this adds to the writings following von Hippel (1988), which emphasise that some users may become of significant importance for innovation processes. On the other hand, the findings of paper II underline that the order of this development can be reverse: rather than always being a market relation that can potentially turn into an innovative relation, firms also establish collaborative innovation projects in order to get access to new customers. In fact, in more than a third of the projects examined in this paper, a main objective was to influence market structure, thus, the partner is chosen (partly) for strategic reasons. In this way, while the market often feeds into innovation processes, the opposite is frequently the case as well.

Finally, the papers highlight that the ability to constantly innovate is a basic necessity in the knowledge economy, and that the response to this pressure can take a variety of forms concerning the character of innovation processes, the type of relations to external partners, etc. In this way, the papers supplement each other as they study the same object (innovation and knowledge creation processes) from different perspectives. The first part of the thesis (papers I-III) examines in detail the importance of geography for interactive knowledge creation. The papers build on analyses of specific industries (cleantech and biotech), however, while the sectoral context is naturally of importance, it is a particular element (the importance of geography in external relations), not the specific industries, which is the main topic of investigation. Conversely, the second part of the thesis (papers IV-VI) takes a broad perspective to understand the development of a specific type of industry (LMT manufacturing), by focusing on a number of issues such as innovation strategies, relations to other industries, and human capital. Consequently, all papers share the fundamental premise that the innovativeness of firms is a key selection criterion in the capitalist selection environment – particularly in the current knowledge economy – and the two parts of the thesis provide supplementary perspectives on this topic.

4.4. Directions for future research

A final element in this comprehensive summary of the thesis is some reflections on future research questions which ought to be addressed. Below, future research topics are briefly described for each of the two parts of the thesis.

Concerning interactive knowledge creation and the importance of multiple proximity dimensions, there is, firstly, an insufficient understanding of the role of power relations. It has been argued that evolutionary economic geography has so far paid little attention to power (MacKinnon et al., 2009), and this issue is also unexplored in relation to Boschma's (2005) proximity dimensions framework. In other words, the influence of power relations on the propensity to form and benefit from partnerships with different degrees and types of proximity is still unexplored.

Secondly and highly related to the first point, a number of structural and contextual factors (e.g. technical capital, social capital, firm size, geographical location and government policy as discussed in section 2.4) influence the ability to choose between partners. Thus, the importance of the different dimensions of proximity is shaped by these factors, but there is currently not a sophisticated understanding of their impact on the characteristics of partnerships along the different proximity dimensions. While maintaining that the motives for partnership formation have significant influence on variation in proximity, the interaction between motives and contextual factors is a challenging but highly interesting topic for future research.

Thirdly, a specific contextual factor which is should be analysed further is the knowledge bases of firms. While previous work has examined the importance of geographical proximity for knowledge flows in industries with different knowledge bases (Martin and Moodysson, 2012), variation in the remaining four proximity dimensions has not been studied so far. Mattes (2011) provides some theoretical reflections on this issue, but some of the findings of paper I contradict these expectations.[22] Therefore, future research needs to provide a thorough empirical analysis of the impact of knowledge bases on the importance of different proximities in collaborations.

Turning to the development of LMT manufacturing in high-wage countries, fourthly, research should examine the role of capital investments in these industries. As mentioned in section 4.2, preliminary results based on Danish data suggest that the capital intensity of low-tech industries increases significantly compared to other types of industries. This is an important aspect to investigate in order to understand the trajectories of these industries. Further, an additional element would be to analyse the geography of capital investments. While it can be expected that investments in human capital and machinery go hand in hand, as qualified labour is needed to control advanced machines, it cannot be ruled out that LMT firms in the periphery prioritise capital investments due to a limited availability of highly skilled labour. Thus, this analysis is also important to fully understand the spatial dimension to the changing character of LMT manufacturing.

Finally, following from the critique of the low-tech/high-tech taxonomy, an additional challenge for future research is to illuminate the heterogeneity within LMT industries. The coarse definition of industries implies that the diversity of economic activity within LMT industries is rarely taken into account by scholars and policymakers: a clothing firm is part of the low-tech category regardless of whether it produces *haute couture* or standardised low-quality apparel. A detailed analysis of the composition of LMT industries, that is sensitive to differences in

[22] The knowledge base of firms is included as a control variable in paper I. Contrary to the conclusion of Mattes (2011), it is found that firms with a synthetic knowledge base are significantly more likely to engage in partnerships with low institutional proximity.

value added, will further underline the unfortunate consequences of a simple taxonomy based solely on R&D intensity.

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PAPER I

Substitution or overlap? The relations between geographical and non-spatial proximity dimensions in collaborative innovation projects

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Abstract

Traditionally, economic geographers stress the impact of geographical proximity in stimulating innovation. Recently, the effects of non-physical dimensions of proximity have been emphasised, as scholars separate between geographical, cognitive, organisational, social and institutional proximity. This paper examines the relations between geography and the non-spatial proximity dimensions by distinguishing between two mechanisms: *the substitution mechanism*, where non-spatial forms of proximity substitute for geographical proximity, and *the overlap mechanism*, where geographical proximity facilitates non-spatial forms of proximity.

The importance of these two mechanisms is analysed in the case of collaborative product development projects in the Danish cleantech industry. Ordered logit models are applied to data on collaborations compiled through interviews. This is complemented by a qualitative analysis that gives specific attention to the relationship between the geographical and institutional dimensions, which stands out as the only relation where the substitution mechanism appears to be of little importance.

Keywords

Proximity, cleantech, collaboration, knowledge linkages, innovation

JEL codes

L69, O31, R11

1. Introduction

This paper is concerned with the relations between geographical proximity and non-spatial forms of proximity – social, institutional, organisational, and cognitive proximity – in collaborative innovation projects. It is now generally accepted in the literature on innovation processes that external knowledge linkages are of significant importance for the innovative capacity of firms, but the effect of geographical proximity on such relations is widely discussed. Traditionally, economic geographers have stressed the effect of geographical proximity and agglomeration economies in stimulating innovative activity (Storper, 1997; Maskell and Malmberg, 1999a; Scott, 2006). According to this view, geographical proximity is not a necessity in collaborations between actors, but it is maintained that geographical proximity has a positive impact on developing non-spatial forms of proximity (Malmberg and Maskell, 2006). Thus, it is argued that there is a significant *overlap* between geographical and non-spatial forms of proximity.

The weight given to geographical proximity has not avoided criticism (e.g. Bunnell and Coe, 2001; Shearmur and Doloreux, 2009). Instead of viewing geography as the predominant dimension shaping collaborative innovation activities, it is suggested that, e.g. social networks can be at least as important for the formation of partnerships as the spatial context where these relations take place (Amin and Roberts, 2008). It has been empirically shown that some types of knowledge linkages are primarily of global rather than local character (e.g. Coenen et al., 2004). Consequently, it is proposed that more attention should be given to the impact of non-physical dimensions of proximity on innovation processes (Torre and Gilly, 2000), with the work of Boschma (2005) separating between geographical, cognitive, organisational, social and institutional proximity being particularly influential (see e.g. Moodysson and Jonsson, 2007; Mattes, 2011). In Boschma (2005), the importance of geographical proximity is downplayed and it is stressed that proximity along other dimensions may reduce coordination costs. Thus, the possibility of *substituting* the non-spatial proximity dimensions for geographical proximity is emphasised.

Accordingly, in the debate on the impact of geographical proximity, the fundamental issue separating these two positions is the relative importance of two mechanisms: *the substitution mechanism*, where non-spatial forms of proximity substitute for geographical proximity, and *the overlap mechanism*, where geographical proximity facilitates non-spatial forms of proximity. The aim of this paper is to empirically assess the importance of these two mechanisms in collaborations between actors. The unit of analysis is collaborative product development projects in the Danish cleantech industry. Ordered logit models are applied to data on 180 inter-firm collaborations compiled through in-depth interviews with cleantech firms. Further, qualitative data from the interviews is analysed to elaborate on the findings from the regression analysis.

The structure of the paper is as follows. The second section reviews the debate on the importance of geography for collaborative innovation and knowledge creation. The third section introduces the theoretical concept of proximity, and the fourth section focuses on the *substitution* and *overlap mechanism*. The fifth section presents the data and methodology, and the sixth section contains the analysis. The seventh and final section concludes and suggestions for further research are provided.

2. Geography and collaboration

It is widely recognised that the globalised world is increasingly shaped by the knowledge economy (David and Foray, 2002). This development is driven by the continuously faster diffusion of knowledge due to advances in information and communication technologies and the increasing long-term knowledge intensity of the economy (Amin and Cohendet, 2004). The acquisition, creation and utilisation of knowledge is now the key factor explaining competitive advantage, as firms must continuously innovate to maintain market shares and profit levels (Nonaka, 1994; Lawson and Lorenz, 1999; Maskell and Malmberg, 1999b).

Associated with the increasing economic importance of innovation is the growing significance of knowledge linkages. Even though the influence of networks varies according to different types of firms, innovation strategies and technological trajectories (Freel, 2003), it is accepted that intra-firm knowledge is generally an insufficient source of innovation, especially as firms increasingly concentrate on core competences. Learning processes are often highly complex, crossing various communities (Amin and Cohendet, 2004; 2005) and fuelled by knowledge inputs adopted from a number of different sources. Thus, interactions and feedbacks from customers and suppliers (Kline and Rosenberg, 1986; von Hippel, 1988) as well as other actors and organisations (Dosi et al., 1988; Lundvall, 1992a; Edquist, 1997) are important for the development of innovations.

It is often argued that geographical proximity has a positive effect on collaborative knowledge creation (e.g. Howells, 2002; Morgan, 2004). The social character of these processes implies that easy communication and interaction between partners are important to the success of collaborations. It is suggested that these features are stimulated by geographical proximity which allows easy face-to-face contact, resulting in trust creation and efficient information transfer (Storper and Venables, 2004). Knowledge creation in geographically delimited networks is an important element in recent theories on endogenous development, from the concept of the innovative *milieux* to innovation systems and industrial districts. To a greater or lesser extent, these contributions stress how localised institutions and routines are critical for promoting innovation through their ability to generate collaborative learning (Brusco, 1982; Piore and Sabel, 1984; Aydalot, 1988; Maillat and Lecoq, 1992; Lundvall, 1992a; Cooke, 2001).

While studies have demonstrated the significant and increasing importance of local knowledge sources for knowledge production (e.g. Jaffe et al., 1993; Audretsch and Feldman, 1996; Sonn and Storper, 2008), knowledge does not flow freely and evenly between firms in agglomerations. Analysing collaboration patterns in an agglomeration, Giuliani (2007) finds that knowledge transfer is a highly uneven and selective process, depending on inter-organisational collaboration patterns. Thus, geographical proximity does not in itself ensure pervasive circulation of knowledge. This draws attention to the social and cognitive relations between firms' employees as well as the indirect role of geography in influencing the conventions that shape interactions between economic agents (Storper, 1997; Gertler, 2003; Smith and Bagchi-Sen, 2006). However, it also highlights how social networks are often more important for inter-organisational partnerships than geographical proximity, and can facilitate collaboration between partners which are geographically distant (Allen, 2000; Saxenian and Hsu, 2001). The importance of such distanciated collaboration is now frequently emphasised (Amin and Cohendet, 2004; Bell and Zaheer, 2007; Fleming et al., 2007) and it is suggested that it is inadequate to view interactions at a particular spatial scale as the key determinant of innovativeness (Bunnell and Coe, 2001). Thus, it is exactly the ability of firms to create, maintain and exploit networks at various scales which is central to innovative capacity (Bathelt et al., 2004; Doloreux, 2004; Wolfe and Gertler, 2004; Maskell et al., 2006; Moodysson, 2008). The proximity dimensions approach proposes a framework for understanding this issue.

3. The proximity framework

The analytical concept of proximity is currently widely applied by scholars seeking to understand the formation and effect of linkages between actors (see Knoben and Oerlemans (2006) for a review). The central idea is that different forms of proximity reduce coordination costs in interactive knowledge creation. While the economic geography literature has traditionally focused on proximity in purely physical terms, Lundvall (1992b) already noted the possibility of substituting organisational proximity for geographical and cultural proximity. The position is further developed in the work of French scholars from the *Proximity Dynamics group* (Torre and Gilly, 2000; Torre and Rallett, 2005), but the model suggested by Boschma (2005) gives the most detailed and thorough account of the relationship between proximity and innovation. Boschma's model contains five dimensions: geographical, cognitive, organisational, social and institutional proximity.

Geographical proximity is defined as both absolute and relative distance. *Cognitive proximity* is associated with differences and similarities in capabilities of economic agents. Differences in the cognitive capacities of actors can make it difficult to learn from each other as the ability to absorb the diffused knowledge is simply not available (Cohen and Levinthal, 1990). *Organisational proximity* refers to the extent of control of relations through intra- or inter-organisational arrangements. The degree of hierarchy has a great impact on the ability to coordinate economic activity and avoid uncertainty and opportunism. *Social proximity* refers to the strength of social ties between agents at the micro-level resulting from friendship, family relations or previous work related interactions. Again, this proximity influences the risk of opportunism, however, here through mechanisms of trust. Finally, *institutional proximity* describes the extent of shared norms, habits, rules and laws between economic agents. Thus, it depends on both the formal and informal *"humanly devised constraints that shape human interaction"* (North, 1992, p. 477). A number of recent empirical studies underline the relevance of such a multi-dimensional proximity framework for the analysis of collaborative innovation processes (Ponds et al., 2007; Balland, 2012; Aguiléra et al., 2012; Broekel and Boschma, 2012).

4. Substitution or overlap?

A key question following from the work of Boschma concerns the role of geography in collaborations between actors. While Boschma notes that geography has an indirect effect, through the facilitation of non-spatial forms of proximity, he stresses the possibility of substituting these proximity forms for geographical proximity. Thus, *"geographical proximity per se is neither a necessary nor a sufficient condition for learning to take place"* (Boschma, 2005, p. 62), as proximity along other dimensions may reduce coordination costs. Further, some degree of cognitive proximity is the only type of proximity which is considered a prerequisite for interactive learning.

In a response to Boschma's (2005) paper, Malmberg and Maskell (2006) acknowledge that collaborations between actors do not necessarily require geographical proximity. However, they maintain that the significant attention given to the effect of geography is exactly due to the indirect impact on *"developing a common institutional, social and cultural setting"* (Malmberg and Maskell, 2006, p. 9). Further, they emphasise that *"['neighborhood effects' will], ceteris paribus, [...] always, in an almost automatic way, tend to create a degree of overlap between spatial and other forms of proximity"* (Malmberg and Maskell, 2006, p. 11).

It follows that the fundamental issue separating the positions of Boschma (2005) and Malmberg and Maskell (2006) concerning the role of geography is the relative importance of two mechanisms: *the substitution mechanism*, where non-spatial forms of proximity substitute for geographical proximity, and *the overlap mechanism*, where geographical proximity facilitates non-spatial forms of proximity. As mentioned in the introduction, the aim of this paper is to empirically assess the importance of these two mechanisms in collaborations between actors. Before proceeding to the analysis, however, it is worth discussing the expectations on the relations between geography and each of the other four proximity dimensions, based on previous studies.

4.1. Geographical and social proximity

The literature suggests that geographical proximity facilitates social proximity. Spatial co-location increases the likelihood of accidental encounters and reduces communication costs. In this way, geographical proximity can stimulate the emergence of trustful relations through repeated exchanges, the possibility of observation and a loss of anonymity (Gössling, 2004; Morgan, 2004; Storper and Venables, 2004). In fact, geographical proximity may be a necessity for some collaborations, as it allows the creation of specific social relations and social proximity (Zeller, 2004). Thus, a strong overlap effect between geographical and social proximity is expected.

Other studies emphasise that social proximity may also substitute for geographical proximity. Collaboration over distance is significantly more likely between individuals with established social relationships (Hansen and Løvås, 2004). Such effects have been identified at both the regional (Agrawal et al., 2006) and the firm level (Corredoira and Rosenkopf, 2010). Practices that strengthen social relations between distanciated partners therefore facilitate collaboration (Frost and Zhou, 2005). Consequently, in addition to an overlap effect, we also expect a substitution effect between social and geographical proximity.

4.2. Geographical and institutional proximity

It is argued that a main effect of geographical proximity on collaborations is through the impact of localised institutions (Gertler, 2010). Conventions tied to specific territories function as coordination principles in interactions between economic agents (Storper, 1997). Institutions underpin collective learning processes and geographical proximity plays an important role in creation and modification of institutions (Kirat and Lung, 1999). Therefore, we expect an overlap between geographical and institutional proximity.

Regarding the substitution effect, some ambiguity is found in the literature. On the one hand, Kirat and Lung (1999) argue that, while institutions are created by actors in geographical proximity, they can subsequently be disseminated, opening up for collaboration over distance. Such collaborations are facilitated by similarities in management culture, attitudes to hierarchy and opinions towards the functioning of partnerships (Saxenian and Hsu, 2001; Bradshaw, 2001). On the other hand, Gertler (2003) suggests that the institutional environment acts as the most important barrier to long-distance collaborations. A case study by Lam (1997) demonstrates how low institutional proximity, resulting from low geographical proximity, cannot be overcome despite long periods of temporary proximity. This suggests that institutional proximity in particular depends on frequent and enduring interactions, thus, geographical proximity is important to maintain institutional proximity over time. Therefore, while it may be possible to substitute institutional for geographical proximity, we expect less of a substitution effect than with social proximity.

4.3. Geographical and organisational proximity

Theoretically, there might be some overlap effect between geographical and organisational proximity: firms may for instance primarily set up subsidiaries close to the headquarters to ease monitoring. However, the importance of this effect can be questioned, and it can furthermore be argued that firms often set up subsidiaries in distant locations to access local markets and knowledge. Thus, we expect no overlap effect between geographical and organisational proximity.

Concerning the substitution effect, it is argued that knowledge flows more easily between individuals within the same firm (Kogut and Zander, 1992). Thus, large corporations can establish internal networks which facilitate collaboration between distant partners (Zeller, 2004). Straightforward communication channels and low uncertainty imply that geographical distance is less problematic in intra-organisational collaborations (Bradshaw, 2001). Consequently, even though organisational proximity does not ensure flawless collaboration (Blanc and Sierra, 1999; Stensheim, 2012), we do expect a substitution effect between organisational and geographical proximity.

4.4. Geographical and cognitive proximity

The overlap effect between geographical and cognitive proximity is shaped by the degree of territorial specialisation. It can be assumed that people working within the same industry generally have greater cognitive proximity than people working in different industries, as the needed capabilities and expertises vary significantly between industries. Thus, members of firm clusters often have similar capabilities, as long as the degree of internal specialisation in the cluster is not too high (Maskell, 2001). Therefore, in the case of industries depending on localisation economies, defined as agglomeration effects internal to the individual industry, we will expect an overlap effect.

With regard to the substitution effect, work on epistemic communities highlight the possibility of distanciated collaboration within such communities (Knorr Cetina, 1999; Amin and Cohendet, 2004). While temporary geographical proximity in the form of occasional meetings is necessary, the cognitive proximity between members resulting from shared expertise within a specific field allows collaboration between community members separated by a great distance in their everyday life (Gertler, 2008; Moodysson, 2008). Thus, we expect that cognitive proximity may substitute for geographical proximity.

5. Data and method

The data for the analysis has been collected through structured interviews with representatives from Danish cleantech firms. While other studies of proximity and innovation are based on data on scientific co-publications (Ponds et al., 2007) or EU-funded projects (Balland, 2012), the interview approach allows an operationalisation of the proximity categories which is closer to Boschma's (2005) framework (see Broekel and Boschma (2012) for a second study of proximities based on interviews). For instance, contrary to studies that measure institutional proximity according to whether actors belong to the same or different organisational form (industry, academia or government), the method applied in this paper takes the informal side of institutions into consideration. Structured interviews have been chosen over questionnaires as much of the gathered information is considered confidential by the interview persons, and several interviewees noted that they were transmitting information which they would not have provided without the trust created by a conversation. Naturally, interviews also allow a greater depth in the data collection process, which the qualitative part of the analysis draws on.

A further reason for the need to build a dataset is the focus on the cleantech sector. This paper follows the definition of the cleantech sector proposed by FORA (2009)[1] as firms that develop and sell products, solutions or technologies that improve the environment – either directly or through a more efficient utilisation of resources. Consequently, firms from all industries can be part of the cleantech sector, but the majority is made up of firms from industries such as renewable energy and green construction. The lack of a cleantech-code in industrial classifications makes it necessary to demarcate the sector in different ways. Used methods are snowball analysis, search for keywords on internet databases and creation of tailor-made software for scanning of firm web pages (The Pew Charitable Trusts, 2009; FORA, 2009). These methods are all labour intensive, resulting in a lack of academic attention to the cleantech sector as a whole in economic geography.[2] Accordingly, most literature on economic development of the cleantech industry is made up of consultancy reports and management books (e.g. Pernick

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[1] FORA is the Danish Enterprise and Construction Authority's division for research and analysis.

[2] Exceptions being Cooke (2008) and Christensen (2009). Numerous studies have dealt with subsections of the cleantech industry from wind energy (Garud and Karnøe, 2003) to fuel cells (Madsen and Andersen, 2010), but few studies analyse the cleantech industry as a whole.

and Wilder, 2008). Thus, there is a need for studies focusing on the opportunities and challenges posed by the emerging green economy (Benner et al., 2011). Further, the cleantech industry is an interesting case for studying relations between proximity dimensions, as it is characterised by a great heterogeneity, encompassing both high- and low-tech firms. Often, partnerships bring together cleantech firms specialised in sustainable technologies with producers of traditional, non-environmentally conscious products.

The population of Danish cleantech firms in this analysis is constructed with the snowball method, supplemented with firm lists from industrial organisations and export promotion agencies, resulting in a total number of 279 cleantech firms which undertake product development. 50 interviews have been carried out with firm representatives (CEOs in small firms; CTOs, CSOs and Development Managers in larger firms) in the period September 2010 to January 2011, equal to a sample size of 17.9 %. The sample reflects the composition of the Danish cleantech industry in terms of firm size (see table 1) and geographical distribution. Following recent interest in projects, as a flexible and adaptive organisational practice (Grabher, 2002; 2004), the main theme of the interviews was the firms' most recently completed product development projects with external partners. Importantly, projects which took the form of knowledge transfer from one partner to another are not included in the analysis, thus, all collaborations are characterised by a collective learning effort. On average, each interviewee described collaborations with between three and four collaborators and the total dataset consists of 180 inter-firm linkages.

Table 1. Employment size distribution

	Interviewed firms (50)	Population (279)
<10 employees	40 %	36 %
10-49 employees	30 %	27 %
50-199 employees	16 %	19 %
>199 employees	14 %	18 %
Total	100 %	100 %

The key data used in this paper describes the distance between the partners according to the proximity dimensions (mean and standard deviations are reported in appendix A). As the interest of the paper is the role of the *substitution* and *overlap* mechanisms in the relations between the geographical and the four non-spatial dimensions, the geographical dimension is the central independent variable, while the remaining four proximity dimensions are the dependent variables.

Taking the location of the respondent's firm as the outset, the *geographical dimension* variable describes the location of the partner separating between the same Danish region, other parts of Denmark, neighbouring countries (Germany, Norway and Sweden), other European countries, and outside of Europe.

As a proxy for the *social dimension*, the interviewees were asked to describe how contact between the partners was initiated (did the partners have ‘personal relations’ or ‘acquaintances’ across the project team, a ‘mutual acquaintance’ outside of the project team or had there been ‘no previous contact’ prior to the project start).

In order to measure the *institutional dimension*, the interviewees were requested to indicate the similarity of the partner’s firm culture in terms of norms and habits compared to their own (on a five-point Likert scale ranging from ‘very large differences’ to ‘no differences’).

The variable for the *organisational dimension* takes a binary form depending on whether the partners are part of the same legal entity or not.

Finally, as a proxy for the *cognitive dimension*, respondents were asked to describe the educational background of the partner’s key employees in the project, separating between ‘same educational backgrounds (e.g. engineers with common specialisation)’, ‘related educational backgrounds (e.g. engineers with different specialisation)’ and ‘different educational backgrounds’.

Additionally, a number of control variables are included in the study. *Location* separates between firms from urban and peripheral parts[3] of Denmark, as the development of Danish industries has followed different trajectories, depending on their location since the mid-1990s (Hansen et al., 2011). *Regional human capital* measures the share of employees with at least bachelor degree at the regional level. *Knowledge base* reflects the critical knowledge base of the firm (see Asheim (2007) for a detailed description of the typology of knowledge bases), as this affects the impact of the different proximity dimensions and the geographical reach of knowledge linkages (Mattes, 2011; Martin and Moodysson, 2012).[4] Firms combine the analytic and synthetic knowledge bases, but in most cases they draw primarily on one of them. In this analysis, firms are assigned a principal knowledge base on the basis of the interviews and the importance the interviewees gave to, e.g. science- and engineering-based innovations as well as the degree of formal education and university training of employees. *Start-up* expresses if a

[3] The urban part is defined as the Greater Copenhagen Area and the three largest cities outside the capital, Aarhus, Odense and Aalborg.

[4] Since the symbolic knowledge base is of limited importance for the majority of the firms in the cleantech industry it is left out of this analysis.

firm is a start-up, here defined as having been established in the period 2005-2010. *Firm size* is measured as the number of employees expressed in logarithms. *Subsector* separates between five sub-sectors of the cleantech industry: renewable energy, smart grid, green construction, waste and water, and transportation. *Technological complexity* accounts for the expected technological complexity of the project prior to initiation, as estimated by the respondents on a five-point Likert scale ranging from 'very large' to 'very limited'. Finally, *Firm* controls for potential effects of having more than one observation for each firm.

As the dependent variables are ordinal, the quantitative analysis is carried out using the polytomous logit universal model (PLUM) in IBM SPSS Statistics version 19. Models are estimated for each of the four dependent variables in order to assess the importance of *the substitution mechanism* (evident when geographically distant collaborations are found to be close in non-spatial terms) and *the overlap mechanism* (evident when geographically proximate collaborations are found to be close in non-spatial terms) in the relation between geography and the other four proximity dimensions. Odds ratios are calculated on the basis of parameter estimates and reported with significance levels and 95 % confidence intervals. A pseudo R^2 measure (Nagelkerke R^2) is reported along with the -2 log-likelihood for the intercept and the final model.

6. Analysis and results

Initially, an overview of the data is provided (table 2). The focal independent variable, *Geographical dimension*, highlights that collaboration processes are subject to strong distance decay effects. The propensity to collaborate with domestic partners is high, while very few partners are found outside of Europe. Concerning the *Social dimension*, a majority of partners have personal relations or are acquaintances, but still nearly one out of four collaborations is between partners that do not know each other and have no mutual acquaintances. On the *Institutional dimension*, it is worth noticing that more than 40 % of the collaborations are characterised by either large or very large cultural differences. Thus, relatively few collaborations are between partners with similar firm cultures. Regarding the *Organisational dimension*, most collaborations are between different organisations, and intra-organisational collaborations are relatively rare. Finally, concerning the *Cognitive dimension*, most of the collaborators have related educational backgrounds, while it is less common to collaborate with partners that have the same educational background.

Table 2. Main variables

	Number	Percentage
Geographical dimension		
0. Outside Europe	10	5.6
1. Rest of Europe	25	13.9
2. Neighbouring country	22	12.2
3. Other Danish region	76	42.2
4. Same region	47	26.1
Social dimension		
0. No previous contact	42	23.3
1. Mutual acquaintance	26	14.4
2. Acquaintance	50	27.8
3. Personal relation	62	34.4
Institutional dimension		
0. Very large differences	14	7.8
1. Large differences	61	33.9
2. Some differences	48	26.7
3. Minor differences	39	21.7
4. No difference	18	10.0
Organisational dimension		
0. Different group	167	92.8
1. Same group	13	7.2
Cognitive dimension		
0. Different educational backgrounds	66	36.7
1. Related educational backgrounds	72	40.0
2. Same educational backgrounds	42	23.3

Appendix table A1 gives the descriptive statistics and correlation coefficients of the variables. The coefficients show that geography is significantly correlated to the other four dimensions: geographical proximity is associated with closer social relations to partners and smaller cultural differences. However, geographical proximity is negatively correlated with organisational and cognitive proximity.

6.1. PLUM

Turning to the regression analyses, table 3 contains the odds ratios of the four models that allow us to assess the importance of the substitution and overlap mechanisms in collaborations between actors.

Table 3. Regression results

High odds ratios indicate high possibilities of being distant in terms of the dependent variable

Proximity dimension	Social dimension		Institutional dimension		Organisational dimension		Cognitive dimension	
	Odds ratio	95 % CI	Odds ratio	95 % CI	Odds ratio	95 % CI	Odds ratio	95 % CI
Geographical dimension (reference = same region)								
Other Danish region	0.85	0.42-1.72	1.19	0.76-1.84	1.68	0.54-5.23	0.82	0.32-2.12
Neighbouring country	2.63*	1.02-6.77	2.46**	1.34-4.52	0.68	0.18-2.55	0.16**	0.04-0.64
Rest of Europe	1.72	0.68-4.37	1.62	0.90-2.90	0.86	0.26-2.89	0.20*	0.06-0.70
Outside Europe	0.13†	0.01-1.19	6.52***	2.75-15.49	0.20*	0.04-0.93	0.29	0.05-1.59
Location (reference = urban)								
Peripheral	4.37**	1.66-11.50	1.35	0.79-2.32	5.50*	1.14-26.38	3.13†	0.89-11.06
Knowledge base (reference = synthetic)								
Analytical	0.63	0.30-1.33	0.51**	0.32-0.81	2.80	0.68-11.53	0.40†	0.15-1.05
Start-up (reference = start-up)								
No start-up	0.68	0.31-1.48	1.77*	1.06-2.95	2.47	0.44-13.88	5.67**	1.69-19.08
Log regional human capital	14.16*	1.77-113.59	2.19	0.70-6.82	23.42*	1.52-360.26	5.46	0.42-71.37
Log firm size	0.54*	0.32-0.91	0.81	0.60-1.10	0.35†	0.12-1.03	0.23***	0.10-0.52
Subsector					***		**	
Technological complexity	†		*				*	
Firm			*				**	
Nagelkerke R^2	0.262		0.266		0.515		0.421	
-2 log-likelihood intercept	440.817		478.976		87.010		359.004	
-2 log-likelihood final	390.361		426.557		44.944		275.429	

† $p < 0{,}10$; * $p < 0{,}05$; ** $p < 0{,}01$; *** $p < 0{,}001$

The first model, *Social dimension*, shows that there is no significant difference between intra-regional partnerships and collaborations across the Danish regions. However, collaborations with partners in neighbouring countries are characterised by high social distance compared to domestic partnerships, confirming the expectation of an overlap effect between geographical and social proximity.

Further, concerning the international partnerships, the odds ratios show that social relations are less close to firms in neighbouring countries compared to those over longer distances: the odds ratio of partnerships outside of Europe indicates that these partnerships are characterised by a high social proximity. Thus, the results confirm the expectation of a substitution effect between social and geographical proximity: while firms have relatively few hesitations about partnering with actors in the neighbouring countries, long-distance collaborations are significantly more likely between partners with established social relationships.

The second model, *Institutional dimension*, suggests that collaborations within the Danish regions are more likely to be between culturally similar partners than partnerships with actors in the neighbouring countries. Collaborations with partners outside of Europe have by far the greatest chance of being characterised by large differences in firm culture. This confirms the importance of the overlap mechanism between geographical and institutional proximity: territorially bound conventions function as coordination principles in collaborations between actors.

Conversely, as the significant odds ratios show that cultural differences increase with distance, the results do not fulfil the expectation of a substitution effect. This questions the suggestion by Kirat and Lung (1999) that the diffusion of institutions can facilitate collaboration over distance. The present analysis of actual collaborations finds little evidence of this effect, thus, the results lend support to the proposal by Gertler (2003) that the main challenge of long-distance collaborations is to overcome institutional differences.

The third model, *Organisational dimension*, highlights that collaborations with partners outside Europe have the greatest chance of being within the same group, while no significant differences can be found between intra-regional partnerships and the remaining three spatial categories. Thus, as expected, there is no overlap effect between geographical and organisational proximity, but a strong substitution effect. While there are no significant differences between the short-distance categories, internal networks can facilitate collaboration between distant partners, and organisational proximity appears to be indispensable for partnerships reaching beyond the boundaries of Europe.

The fourth model, *Cognitive dimension*, shows that intra-regional partnerships are relatively unlikely to be between partners with similar educational backgrounds. In fact, intra-regional collaborations are the least likely to have a high cognitive proximity. Thus, there is no overlap effect between geographical and cognitive proximity, indicating that the Danish cleantech sector is not depending on localisation economies in the form of local specialised networks.[51] On the contrary, the results indicate that shared capabilities and expertise facilitate long-distance collaborations: the international collaborations are far more likely to have a high degree of cognitive proximity than the intra-regional collaborations. This confirms that cognitive proximity may substitute for geographical proximity.

Concerning the control variables, it is worth noticing that high levels of regional human capital are strongly associated with collaborations characterised by low social and organisational proximity. Further, the partners of large firms are generally proximate along the different non-spatial dimensions. Finally, it is in particular interesting to note that firms with a synthetic knowledge base are more likely to engage in partnerships with significant cultural differences. This shows how the ability to collaborate despite different norms and habits is important for firms that innovate through the ability to synthesise different forms of knowledge. However, this finding contradicts the hypothesis suggested by Mattes (2011) in a theoretical contribution, where she argues that shared norms and values are especially important for firms with a synthetic knowledge base. Thus, this points to the need for further research into the relation between knowledge bases and proximity in collaborations.

Summing up, table 4 gives an overview of the importance of the substitution and overlap mechanisms. While the results generally correspond to our expectations, the apparent inability to substitute institutional proximity for geographical proximity remains an interesting point. The analysis of this issue is elaborated in the following section based on qualitative data from the interviews, which give us a more detailed understanding of the relationship between the geographical and institutional dimensions.

Table 4. Overview – substitution and overlap

	Substitute for geographical proximity	Overlap with geographical proximity
Social proximity	Yes	Yes
Institutional proximity	No	Yes
Organisational proximity	Yes	No
Cognitive proximity	Yes	No

[51] It may rely on other forms of localised benefits, e.g. access to a shared labour pool.

6.2. The geographical and institutional dimensions

Returning to the argument of Kirat and Lung (1999), they propose that institutions created by actors in geographical proximity can subsequently be disseminated, opening up for collaboration over distance. The channels of dissemination are of particular importance here, and Kirat and Lung (1999) emphasise the links between producers and suppliers as a key relation in this process. Further, they consider that these relations are characterised by learning between the diffusing and adopting actors. In this way, the diffusion of institutions is considered to be depending on social interaction. This raises the question of the role of social proximity in facilitating institutional proximity in geographically distanciated relations.

The interviews show that the relatively few collaborations with both a high institutional proximity and a low geographical proximity are in fact most often between partners with a high social proximity. The partnership between a Danish green construction firm and a Swiss research institution exemplifies this point. The two partners have collaborated over a number of years on different projects. According to the Technical Manager, the relation was initially complicated due to cultural differences and language barriers. Therefore, a targeted effort was made to build strong social relations, particularly between the project managers, through frequent and regular telephone and physical meetings. As a result, while there are still considerable cultural differences between the two organisations in general, then there are now hardly any differences in the way the team members are working. The relation between a Danish engineering firm within renewable energy and an Irish energy provider has similar characteristics: Again, a number of previous collaborations preceded this project, and personal relations were established. The Chairman of the Board of the Danish firm describes the cultural similarities in the following way: *"We have very similar cultures... [T]hey are very large, they build fossil fuelled power plants in [lists several countries], but the engineering group we work with has with time become interested in our niche technology and our way of working."*

These cases highlight the impact of social proximity in dissemination of institutions, and it is important to note the order of events: the initial development of social proximity allows the construction of institutional proximity – not vice versa. In both examples, the diffusion and adoption of institutions are facilitated by close social relations between the partners. According to the interview person in the second example, the roles of diffuser (the engineering firm) and adopter (the energy provider) are clearly identifiable in this case; however, this distinction is often less clear. This is illustrated by a relationship between two collaborators from the wind turbine industry in respectively Denmark and the United States which goes more than a decade back. According to the Danish Research Engineer, the Americans have traditionally had a greater focus on compliance to rules and anticipation of new regulatory demands. He explains: *"That's probably where the greatest difference was… Of course we have to care about the safety factors.*[62]*We were used to take the safety factors from the certification authority without considering the final needs of the customer – and of other potential customers... [T]hen we had to deal with those problems later."* On the other hand, he also notes how the greater creativity and flexibility on the Danish side has influenced the work habits of the Americans. Thus, in this case, the increasing institutional proximity is not a result of a diffusion of firm culture from one partner to the other, but rather a process where the actors take on the roles of diffuser and adopter simultaneously. Still, in this case, initial social proximity is a prerequisite for the institutional alignment to take place.

Finally, it is worth emphasising that the high institutional proximity in these cases of long-distance collaboration is highly valuable for the outcomes of the projects. This is evident in the previous case, and it is also obvious in the collaboration between a Danish supplier from the wind turbine industry and a British research group. The Danish CEO explains that *"[the work cultures] are extremely similar... [I]f someone has an idea, then it's being tested. Things go very fast and it is highly experimental... I can't imagine a better collaboration."* Naturally, the ability to collaborate quickly and smoothly is often considered an advantage of partnerships between collaborators located in geographical proximity, thus, the present example indicates that institutional proximity may substitute for geographical proximity.

Summing up, the findings of the PLUM analysis are modified on the basis of the qualitative analysis. There is indeed a substitution effect between institutional and geographical proximity, however, social proximity is an essential intermediate in this relation. Further, the instances where institutional proximity substitutes for geographical proximity are few and far between, thus, the substitution mechanism is of relatively low importance in the relation between the geographical and institutional dimensions.

7. CONCLUSION

This paper sets out to analyse empirically the relationship between geographical and non-spatial forms of proximity in collaborative innovation processes. The theoretical outset is taken in the different conceptions of the importance of geographical proximity for such relations. It is argued that the differences rest on divergent opinions concerning the relative importance of two mechanisms: *the*

[62]The safety factor is the relation between the strength of the component and the load on the component.

substitution mechanism, where non-spatial forms of proximity substitute for geographical proximity, and *the overlap mechanism*, where geographical proximity facilitates non-spatial forms of proximity.

Based on an empirical analysis of the characteristics of collaborative innovation projects in the Danish cleantech industry, support is generally found for the expectations extracted from previous studies dealing with geographical and non-spatial proximity dimensions. The findings indicate that the relation between the geographical and social dimensions is influenced by both the substitution and overlap mechanisms. Concerning the organisational and cognitive dimensions, no evidence is found for the overlap effect, but only for the substitution effect. Conversely, the regression analysis highlights that while the geographical and institutional dimensions overlap, there is no indication of a substitution effect in this relation. However, as discussed at length in the qualitative part of the analysis, the interviews indicate that it is indeed possible to substitute institutional proximity for geographical proximity, but these instances are relatively rare, presumably partly because social proximity is an essential intermediary in these cases. Thus, while it exists, the substitution mechanism is of relatively low importance in the relation between the geographical and institutional dimensions, supporting the suggestion of Gertler (2003) that the main challenge of long-distance collaborations is to overcome institutional differences.

A point worth stressing is the lack of significant differences in the regression analyses between intra-regional partnerships and collaborations across the Danish regions. This suggests that the overlap effect applies to collaborations with Danish actors in general, rather than specifically with actors from the same region. This inability to measure significant differences may be explained by the relatively small size of the Danish regions and the highly specialised character of most of the innovation processes, which limits the number of potential partners within the country. Thus, concerning the Danish cleantech industry, it appears to be more relevant to discuss the character of the national innovation system rather than the regional.

In addition to the empirical findings of the paper, it also has a conceptual contribution to future research on the geography of collaborations, by explicitly distinguishing between the overlap and substitution mechanism. Often, empirical analyses within this field fail to recognise the potential simultaneous importance of these two effects. Some studies, with a point of departure in territorial analysis, tend to overemphasise the underpinning effect of geography on other forms of proximity, while other traditions, with an aspatial foundation, fail to acknowledge the distinct influence of geographical context on network structure and development. Thus, it is argued in this paper that it is necessary and important to approach research questions within this topic with an awareness of the existence of both mechanisms.

Finally, acknowledging the limitations of this paper, several challenges for future research remain. There is a need for analysing the importance of overlap and substitution mechanisms across different types of industries. While the cleantech sector is very heterogeneous in terms of, e.g. the research intensity of the firms, it is also characterised by frequent collaborations that bring together actors with knowledge on sustainable practices and traditional production techniques. Studies with a focus on inter-industrial differences are required to examine the potential impact of this characteristic. Moreover, this paper has analysed one type of interaction, namely collaborative innovation projects. A second strand of research worth pursuing is to extend this analysis to more informal types of collaborations (see e.g. Trippl et al., 2009), which might show different relations between geographical and non-spatial proximity dimensions.

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APPENDIX A

Table A1. Correlation coefficients between the variables

	Mean	S.D.	1	2	3	4	5	6	7	8	9
1. Social dimension	1.73	1.17									
2. Institutional dimension	1.92	1.13	0.15*								
3. Organisational dimension	0.07	0.26	0.33***	-0.15*							
4. Cognitive dimension	0.87	0.76	0.28***	0.04	0,13†						
5. Geographical dimension	2.69	1.16	0.15*	0.16*	-0,16*	-0,15*					
6. Location firm	0.53	0.50	0.14†	-0.03	-0,04	0,05	0.12				
7. Knowledge base firm	0.61	0.49	-0.10	-0.19**	0,18*	-0,15*	-0.12	-0.31***			
8. Start-up	0.27	0.45	-0.19**	0.12	-0,07	0,06	0.02	-0.23**	-0.10		
9. Log regional human capital	-0,97	0.20	-0.05	-0.02	-0,19*	-0,03	0,10	0,59***	-0,33***	0.02	
10. Log firm size	1.07	0.73	0.10	-0.09	0,26**	0,05	-0.15*	-0.19**	0.19*	-0.30***	-0,20**

† $p < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

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PAPER II

Juggling with proximity and distance. Collaborative product development in the Danish cleantech industry

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Abstract

Studies increasingly apply a multidimensional proximity framework in the analysis of collaborations between actors. This paper explores the variation in the proximity characteristics of collaborations based on 50 interviews with representatives from Danish cleantech firms. Drawing on organisational theory on partnership formation, the paper emphasises how collaboration objectives are a key factor explaining the variation along the proximity dimensions in partnerships. In this way, the analysis distinguishes between the types of collaboration where geographical proximity is highly important, and those where non-spatial forms of proximity may substitute for it. The insight that firms use distance and proximity as strategic tools to achieve certain objectives highlights how the proximity framework can be applied as a dynamic concept in the analysis of firm decision-making.

Keywords

Proximity, distance, collaboration motives, partnership formation, cleantech

1. Introduction

This paper is concerned with proximity and distance in collaborations between actors. Knowledge linkages are of significant importance for innovation and growth, and scholars increasingly give attention to the relationship between proximity and partnership formation. A number of recent theoretical (Torre and Gilly, 2000; Boschma, 2005; Mattes, 2011) and empirical (Ponds et al., 2007; Boschma et al., 2009; Eriksson, 2011; Hansen, 2011; Balland, 2012; Broekel and Boschma, 2012) contributions highlight the importance of partnership characteristics along multiple dimensions of proximity for knowledge flows and collaborations. These studies have provided important insights into the interrelationship between different proximity dimensions, and the influence of these dimensions on partnership formation. The current analysis contributes to this body of literature in two ways.

Firstly, the paper specifically aims at explaining variation along proximity dimensions in collaborations by analysing processes of partner selection in collaborative product development projects. Surprisingly, few contributions examine the influence of collaboration motives on search criteria and the resulting partnership characteristics at the dyad-level. This is also the case for previous empirical studies applying the proximity framework, as they do not examine the process of making choices concerning the formation of linkages at the scale of the firm. Rather, they follow a quite similar methodological approach: data on a certain type of collaborations is collected and analysed quantitatively, providing insights into the effect of different proximity dimensions on the formation of firm partnerships. This paper digs deeper than the analysis of partnership attributes at an aggregated level and examines how the objectives of the partnerships influence the variation in geographical, cognitive, organisational, social and institutional proximity. In this way, the paper not only analyses the resulting partnerships, but it also examines the processes at the earlier stage, before agreements to collaborate are reached. Thus, applying an analytical perspective that highlights the strategic choices of firms, the paper follows Glückler (2007) who underlines the need for analysing processes of tie selection in economic geography.

Secondly, through the focus on collaboration objectives and proximity variation, the paper seeks to increase the understanding of when geographical proximity matters for collaborations between actors. Naturally, this topic has been widely debated, with many authors arguing for the importance of geographical proximity for collaboration (e.g. Piore and Sabel, 1984; Howells, 2002; Teixeira et al., 2008), while others stress that different forms of proximity can also facilitate partnerships (e.g. Mowery et al., 1998; Kirat and Lung, 1999; Ahuja, 2000). The paper analyses the importance of geographical proximity according to different collaboration motives to identify the types of collaborations where geographical proximity is highly important.

Hence, the main research question addressed in this paper is: *How do collaboration motives influence the partner selection process and the resulting partnership characteristics in product development projects?* It is argued in the paper that firms use distance and proximity as tools to achieve certain objectives. The search criteria differ between firms as well as within the same firm depending on the purposes of the collaborations. Firms will explicitly seek partners inside the local area in some instances, explicitly partners outside the local area in other. The analysis highlights that geographical proximity plays an important role in collaborations at the core of innovation processes which aim at assessing complementary technologies, obtaining knowledge or reducing innovation time-span, while long-distance relations appear to be important for collaborations motivated by market access and cost considerations. In this sense, firms are juggling with proximity and distance depending on the motives for collaborating.

The findings, drawing on 50 in-depth interviews with representatives from Danish cleantech firms on recently completed collaborative product development projects, illustrate the value of a conceptual approach combining insights from economic geography and organisation theory. This theoretical point of departure is presented in the second section. The third section outlines the empirical setting and the research design. The fourth section contains the main analysis of the impact of collaboration motives on variation in proximity and distance. The final section concludes.

2. Conceptual framework

The conceptual framework of this paper includes two bodies of literature. The paper seeks to contribute to the economic geography literature on proximity dimensions. In order to do so, analytical concepts from organisation theory on the rationale behind collaborations between actors are applied. This combination highlights how collaboration processes differ according to spatial and non-spatial dimensions of proximity, and it emphasises how the selection of partners varies according to the objectives of the collaborations. In this way, the proximity framework is applied as a dynamic concept that assists in the analysis of firm decision making.[1]

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[1] The author recognizes that not all firms have equal possibilities to choose between partners. Factors such as technical capital (Stuart, 1998), social capital (Gulati, 1995), firm size (Rosenkopf et al., 2001), geographical location (Drejer and Vinding, 2007) and government policy (Arranz and de Arroyabe, 2008) act as filters in the selection process, making some options unlikely or unfeasible. For instance, a well-connected firm with excellent technical capabilities located in a dynamic cluster is in a different position than a start-up with an unproven track record located in the periphery. However, as social science is always concerned

2.1. Proximity dimensions

During the last decades, a substantial body of literature within economic geography and related disciplines has underlined the beneficial impact of geographical proximity on knowledge production and innovation. In addition to agglomeration effects, which do not necessitate interactions between localised actors, geographical proximity may also influence collaborations between actors (Knoben, 2009). It is argued that the exchange and interpretation of information is more difficult in dispersed relations (Cramton, 2001), thus, collaborations with geographically close partners are associated with successful outcomes (Teixeira et al., 2008). Still, certain factors may facilitate collaborations over distance, such as intra-organisational networks (Sole and Edmondson, 2002; Zeller, 2004), established social relationships (Hansen and Løvås, 2004; Corredoira and Rosenkopf, 2010), common institutional frameworks (Kirat and Lung, 1999; Saxenian and Hsu, 2001), and shared cognitive frameworks by, e.g. members of epistemic communities (Knorr Cetina, 1999; Amin and Cohendet, 2004).

To account for these factors, several multi-dimensional proximity frameworks have been proposed (e.g. Torre and Gilly, 2000; Zeller, 2004; Knoben and Oerlemans, 2006). The framework by Boschma (2005) gives a detailed and thorough reasoning for the inclusion of five proximity dimensions. He argues that the interplay between geographical, cognitive, organisational, social and institutional proximity has a profound influence on interactive innovation processes. Thus, collaborations are characterised by differences in the physical distance between actors (geographical dimension), the extent of similarity in knowledge bases (cognitive dimension), the degree of common ownership (organisational dimension), the strength of social ties (social dimension), and the extent of shared norms, habits, rules and laws (institutional dimension). Proximity along each of these dimensions facilitates interaction and reduces coordination costs, but too much proximity can be detrimental and may lead to situations of lock-in (Bathelt et al., 2004; Boschma, 2005). This proposition is closely related to the concept of optimal cognitive distance, which suggests that an intermediate level of differences in knowledge bases is beneficial in collaborations between actors, as it balances understandability and degree of novelty (Nooteboom, 1999). Thus, while it is generally easier to form partnerships with proximate actors, this type of collaborations may not increase innovativeness. Termed the proximity paradox by

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with the functioning of open systems, it is necessary to abstract from some aspects in order to be able to focus on other relations. While the influence of these factors on partnership formation is an interesting area for future research, this paper focuses on collaboration objectives.

Boschma and Frenken (2010), this position highlights how some degree of distance is considered a desirable feature in collaborations between actors.

A number of empirical studies have dealt with the relationship between the different proximity dimensions and the formation of partnerships. Ponds et al. (2007) find that geographical proximity is highly important in collaborations characterised by large institutional distance, while less so in partnerships between institutionally proximate collaborators, indicating that one dimension of proximity can substitute another. The results of Balland (2012) suggest that geographical, institutional and organisational proximity facilitate partnership formation while social and cognitive proximity have no significant effects. In a similar study, Broekel and Boschma (2012) find that all four types of proximity analysed (leaving out institutional proximity) promote partnership formation. They also measure the outcome of the relations and observe that cognitive and organisational proximity have negative impacts, while geographical and social proximity have positive effects. Thus, they conclude that the proximity paradox only exists for the two first types of proximity.

These empirical studies underline the relevance of a multi-dimensional proximity framework for the analysis of collaborative product development processes. However, they also point to an insufficiency in the current proximity literature, as variation along proximity dimensions in collaborations between actors is not taken into account. Reflecting this, Huber (2011, p. 3) recently noted that *"it remains an empirical question which type and which degree of proximity is vital for knowledge networks"*, but no mention is made of variation in proximity.

A second critique of the proximity literature is that it considers geographical proximity on line with the non-spatial dimensions, even though geographical proximity primarily influences collaboration indirectly by facilitating proximity along the other dimensions (Malmberg and Maskell, 2006). Geographical proximity strengthens social ties, promotes the creation of shared institutions, and reinforces cognitive similarities. Thus, in reality it might be more difficult to substitute non-spatial proximity for geographical proximity than suggested by Boschma.

This paper uses insights from organisational theory on collaboration motives and partner selection to examine these issues, as the required forms of proximity may vary according to collaboration motives. Further, this approach makes it possible to identify the types of collaborations where geographical proximity is highly important and those where other forms of proximity may substitute for it.

2.2. Collaboration motives

The general increase in partnerships over time (Hagedoorn, 2002) has been accompanied by an increase in the literature on the relationship between networks and innovation (Ozman, 2009). An important topic is the motives of firms to engage in collaborations. Considering collaborations, broadly defined, Oliver (1990) identifies six critical contingencies that explain the motivations of actors to collaborate: necessity, asymmetry, reciprocity, efficiency, stability, and legitimacy. However, as noted by Oerlemans and Knoben (2010), these factors are not all equally important for relations concerned with knowledge production and innovation. Thus, a number of different theoretical approaches such as transaction cost economics, the resource-based view of the firm, and dynamic capabilities have developed alternative frameworks for understanding partnership formation within this specific area (Hemphill and Vonortas, 2003). With different starting points, the theories provide valuable insights that nevertheless have led to a fragmented research field. On the one hand, transaction cost economics emphasise the high costs of in-house technological development within multiple fields and the inability to create complete contracts due to the activities' uncertainty. On the other hand, theories on strategic incentives stress the opportunity for accessing or acquiring competences and knowledge held by collaborators.

As a result, several calls for an integrated theoretical perspective on partnership formation have been made (Osborn and Hagedoorn, 1997; Hemphill and Vonortas, 2003). In line with this, it has been shown that there is not a single theory which covers the different types of information evaluated by managers concerning potential collaborations (Tyler and Steensma, 1995). Therefore, a perspective that combines the different theories is necessary to understand partner selection. The work of Hagedoorn has in particular been influential in synthesising the contributions of the various theories in a common framework (Hagedoorn, 1993; Hagedoorn et al., 2000). He distinguishes between seven motives underlying technology cooperation, which both take access to concrete resources such as skills and capital, and abstract resources in the form of legitimacy and market power (Eisenhardt and Schoonhoven, 1996) into consideration. Obviously, a firm has often several motives for engaging in a partnership, and the incentives of different firms taking part in the same partnership may also vary (Klijn et al., 2010). The motives are:

1. High costs and risks of R&D
2. Lack of sufficient financial resources
3. Technological complementarity
4. Reduction of innovation time-span
5. Performing basic research
6. Influencing market structure
7. Monitoring technological opportunities

This framework is applied in the current paper's analysis to examine the influence of collaboration motives (following Hagedoorn, 1993) on the configurations of partnerships along the proximity dimensions (following Boschma, 2005).

2.3. Collaboration motives and partner selection

While there is a rich literature on partnership formation focusing on issues such as the importance of former collaboration (e.g. Guimerà et al., 2005) and technological credibility (e.g. Stuart, 1998), surprisingly few contributions examine the influence of collaboration motives on partner selection, considering that Geringer (1991) showed more than 20 years ago that this is a crucial factor for partnership formation. A call for research on the role of motives in partner selection by Shah and Swaminathan (2008) is in particular valid concerning collaborative product development projects. A recent review of the literature on collaborative product development deals specifically with partner selection, but does not mention the role of collaboration motives (Büyüközkan and Arsenyan, 2012). Thus, the influence of motives on search criteria and the resulting partnership characteristics is so far unexamined in this type of relations.[2]

Consequently, to find contributions examining the relation between collaboration motives and partner selection, one has to turn to studies of formal collaboration types with a longer time horizon, in particular joint ventures. Early contributions (Glaister and Buckley, 1996; Glaister and Buckley, 1997) focused on the importance of factors such as partner size, and industry on the changing importance of strategic motives and selection criteria (and generally found little significant variance), but recent studies analyse the characteristics of the collaborations at the dyad-level. While few in number, some important conclusions arise from this literature. Dong and Glaister (2006) show that trust and prior ties (i.e. high social proximity) are particularly important when the aim of the partnership is cost and risk reduction. Nielsen (2003) finds that partnerships motivated by a need for accessing technological expertise are likely to be non-equity joint ventures rather than equity joint ventures (i.e. low organisational proximity). Further, a number of studies suggest that market knowledge and access are the prime motivations for Western firms to engage in long-distance collaborations with partners in emerging economies (Hitt et al., 2000; Tatoglu and Glaister, 2000; Dong and Glaister, 2006).

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[2] A notable exception being Miotti and Sachwald (2003) who analyze R&D collaborations of research intensive French firms. However, they only separate between technology and cost driven collaborations, and US and EU partners. Their results indicate that cost-driven R&D collaborations are primarily with EU partners, while partnerships motivated by access to technology are primarily with US partners.

The literature on university-industry relations has also taken up this topic recently. Schartinger et al. (2002) analyse the importance of geographical and cognitive proximity, but they do not distinguish between different types of collaborative projects and instead compare this activity to, e.g. contract research. Thus, for this paper's analysis, the results of Broström (2010) are more relevant, as he finds that geographical proximity has a particularly positive effect on university-industry relations that focus on learning.

It follows from this review that, firstly, very few contributions are concerned with the relation between collaboration motives, search criteria and partnership characteristics. For instance, no studies have examined the possible varying importance of cognitive proximity depending on collaboration motives. However, the analysis of Nooteboom et al. (2007) indicates that the inverted U-shaped effect of cognitive distance on innovation performance is stronger in the case of partnerships dealing with exploration than those focusing on exploitation.[3] The possibility of detecting differences according to the coarse distinction between exploration and exploitation encourages a detailed examination of the varying importance of cognitive (as well as the other forms of) proximity according to collaboration motives.

Secondly, existing studies focus on other types of relations than collaborative product development projects, particularly joint ventures. Thus, little is known about the influence of collaboration motives on partner selection in projects which are characterised by a greater flexibility and temporal limitation (Grabher, 2002). The differences separating these types of relations imply that conclusions cannot be directly transferred between them. Consequently, there is a need for analysing the importance of proximity according to different collaboration motives in product development projects.

On this background, the research question that this paper seeks to answer is the following: *How do collaboration motives influence the partner selection process and the resulting partnership characteristics in product development projects?* Considering the limited amount of existing literature dealing with this topic, the nature of this study is exploratory, applying Hagedoorn's (1993) taxonomy of motives to analyse the choice of partners, and provide insight into the varying importance of proximity. Thus, the first contribution of this paper is to fill a gap in the current proximity literature by examining the causes of this variation. Through this analysis, the second contribution of the paper is to increase the understanding of when geographical proximity matters for collaboration between actors.

[3] Following the classical distinction by March (1991).

3. EMPIRICAL SETTING AND RESEARCH DESIGN

The study analyses collaborative product development projects in the Danish cleantech industry. Denmark has traditionally been an early adopter of environmental technologies and today it maintains this position as a leading cleantech nation on a global scale. According to consultants Roland Berger, the value added of the Danish clean energy technology industry contributes to 3.1 % of Denmark's gross domestic product (GDP) – more than twice the contribution of Chinese cleantech firms to the GDP of China which is ranked second in the world (van der Slot et al., 2011). The wind turbine industry is a main driver of the Danish cleantech industry through the presence of the global leader within the industry, Vestas, as well as the wind power division of Siemens. In addition to R&D centres of other global wind turbine producers, the network of suppliers and consultants is highly specialised. Other cleantech areas with significant concentrations of firms include energy efficiency (e.g. Danfoss and Rockwool) and water management (e.g. Grundfos).

In this paper, cleantech firms are defined as firms that develop and sell products, solutions or technologies that improve the environment – either directly or through a more efficient utilisation of resources (FORA, 2009).[4] Consequently, even though most firms come from industries such as renewable energy, water filtration and green construction, the definition does not exclude firms from industries which are generally not considered part of the cleantech sector (e.g. ICT and automotive) if the firms compete on the basis of green solutions. This point towards the increasingly pervasive environmental focus across industries which is also reflected in the collaboration patterns of cleantech firms. Partnerships often bring together cleantech firms specialised in sustainable technologies with producers of traditional, non-environmentally conscious products. This contributes to make it interesting to analyse collaborative product development processes in cleantech firms. Still, Bakker et al. (2011) report considerable inter-industrial variation in the prevalence of such projects, thus, the conclusions of the analysis should not be uncritically transferred to other contexts.

3.1. METHOD

The analysis is based on 50 interviews with firm representatives from Danish cleantech firms in the period September 2010 to January 2011, all carried out by the author of the paper. Interviews were chosen as a method for several reasons. Firstly, the collected information is often considered highly sensitive by the inter-

[4] FORA is the Danish Enterprise and Construction Authority's division for research and analysis.

view persons. It was emphasised on several occasions by the interviewees that they were transmitting information on collaborators which they would not have provided without the trust created by a conversation. Secondly, the interview approach allows an operationalisation of the proximity categories which is close to Boschma's (2005) framework. For instance, contrary to studies that measure institutional proximity according to whether actors belong to the same or different organisational form (industry, academia or government), the informal side of institutions is considered in this paper. Thirdly, interviews allow a great depth in the data collection process which makes it possible to get a detailed understanding of the relation between collaboration motives and partner selection.

Besides from being part of the cleantech industry, firms were furthermore required to undertake product development. Thus, service and technology providers, utility firms and retail businesses were not considered for the interviews, resulting in 279 potential interview firms. The 50 interviewed firms were selected randomly; however, it was ensured that the sample reflects the composition of the Danish cleantech industry in terms of firm size (table 1) and geographical distribution.

Table 1. Employment size distribution

	Interviewed firms (50)	Population (279)
<10 employees	40 %	36 %
10-49 employees	30 %	27 %
50-199 employees	16 %	19 %
>199 employees	14 %	18 %
Total	100 %	100 %

In the smaller firms, interviews were typically conducted with Chief Executive Officers (CEOs), while Chief Technology Officers (CTOs) and Development Managers were interviewed in the larger firms. All interviews were audiotaped and the duration varied between 45 and 105 minutes. The main theme of the interviews was the firms' most recently completed product development projects with external partners. In total, relations to 180 external partners were described. Importantly, projects which took the form of knowledge transfer from one partner to another were not included in the analysis, thus, all collaborations are characterised by a collective learning effort. For each partnership, questions were asked to clarify the rationale and content of the collaboration, the roles of the involved partners, the nature of interaction, as well as the distance between the partners according to the five proximity dimensions.

The questions ranged from those that sought closed ended responses, to more open semi-structured questions that allowed respondents to expand on selected themes. Questions concerning the degree of proximity in the partnerships had closed answers. Control can be an issue in interviews with business leaders as they are used to exercise authority over others, and closed questions were therefore chosen to ensure clear answers on these central issues (Schoenberger, 1991; see also Crang, 2002). Concerning the *geographical dimension*, answers separate between partner location in the same Danish region, other parts of Denmark, neighbouring countries (Germany, Norway and Sweden), other European countries, and outside of Europe. Regarding the *social dimension*, interviewees were asked to describe how contact between the partners was initiated (did the partners have 'personal relations' or 'acquaintances' across the project team, a 'mutual acquaintance' outside of the project team or had there been 'no previous contact' prior to the project start). On the *institutional dimension*, the interviewees were requested to indicate the similarity of the partner's firm culture in terms of norms and habits compared to their own (on a five-point Likert scale ranging from 'very large differences' to 'no differences'). In regards to the *organisational dimension*, a distinction was made depending on whether the partners were part of the same legal entity or not. Finally, concerning the *cognitive dimension*, respondents were asked to describe the educational background of the partner's key employees in the project compared to their own participating employees, separating between 'same educational backgrounds (e.g. engineers with common specialisation)', 'related educational backgrounds (e.g. engineers with different specialisation)' and 'different educational backgrounds'.

Importantly, answers to these closed questions were supplemented by open semi-structured questions which asked the interviewees to elaborate on these characteristics. For instance, in the case of low cognitive proximity, respondents would be asked if there were any consequences of this, if it was a desirable feature, if it was coincidental, etc. This combination of questions made it possible, on the one hand, to establish a clear picture of the degree of proximity in each partnership, while, on the other hand, allowing access to the rich data on which much on the analysis is based.

The interview material was processed right after each interview, which is in reality the first phase of the analysis, as notable relations and quotes were marked. When possible, information provided during the interviews was verified through press releases and articles from industrial journals. Upon completion of data collection, observations were sorted according to the conceptual framework adopted from organisational theory, differentiating between seven objectives underlying technology cooperation between firms (Hagedoorn, 1993). A detailed transversal analysis along these categories was performed which led to a modification of the framework, reducing the number of categories from seven to five. Firstly, the decision to develop basic research partnerships is considered a result of one or more of the other motives (e.g. need to share costs and risks) rather than an individual motive. Secondly, no distinction is made between high costs and risks of

R&D, and lack of sufficient financial resources, as it is found that if a firm needs to share the high costs and risks of R&D then it results from a lack of financial resources.[5]

Having identified the five relevant objectives, the analysis was structured according to these five categories. In the final stage of the research process, the different proximity dimensions were analysed individually for each of the five categories. By carefully going through the observations within each category, paying attention to answers to both open and closed questions, the relations between the motives and proximity along the different dimensions became clear. A considerable number of quotes from the interviews, that represent these relations and explain the rationale behind them, are included in the analysis. In this study, the approach leads to an empirical validation of the role of objectives as a significant factor influencing the resulting characteristics of the partnerships, according to the proximity dimensions.

4. Juggling – choosing between close and far

While the ability to choose among partners is subject to constraints, the following analysis highlights the impact of collaboration motives for partner selection. The most frequent reasons behind the collaborations were a need for *assessing complementary technologies* (44 %) and *influencing market structure* (37 %). *Obtaining knowledge* was a main incentive in 28 % of the partnerships while 22 % sought a *reduction in the innovation time-span*. The need to *share costs and risks* was an important motive in 11 % of the collaborations. These five motives are analysed individually below. While the current economic geography literature is the theoretical point of departure for this analysis, it is interesting to note that the conclusions are in fact also acceptable if the questions are approached from conventional economic theory. Thus, although the paper is a single-sector study, this supports the general validity of the analysis. The final paragraph of each subsection takes such a conventional economic perspective.

4.1. Assessing complementary technologies

Increasing technological complexity as well as the demand for considering environmental issues in a growing number of industries implies that many partnerships result from a need to bring actors with different technological competences

[5] It should be stressed that it may well make sense to distinguish between these categories in other studies. However, it is part of the research process to critically examine theoretical frameworks, rather than uncritically adopt them. In this paper, the five categories appeared as relevant, based on the analysis of the empirical material.

and skills together. These collaborations primarily gather firms from very different technological background. Firms that possess practical knowledge will often explicitly seek out partners with relevant theoretical knowledge, and vice versa. Thus, in these collaborations, firms seek partners with a low cognitive proximity and in some cases they specifically look for differences in the individual mental representations of theory (Balconi et al., 2007). While such characteristics may not be the most beneficial for firm partnerships in general, large cognitive differences can be a desirable feature in these types of collaborations. The decision by a high-tech green construction firm to initiate a partnership with an architectural agency illustrates this well. Explaining why the firm selected this partner for the project, the Technical Manager refers directly to cognitive differences: *"In science, all terms have to be well-defined and accurate, but it's a quality for them if terms can be mixed... [I]t can be difficult and we need to use many words to explain things that are simple to us, but they get associations that we would never have got... often they get inspired by a single word in a subordinate clause... [T]he piano plays differently when you press their keys."*

Naturally, there are also costs associated with this type of collaborations, as it is also evident from the quote above. In this case, the two firms are located in the same region and they knew each other before the project was initiated. Both factors had a positive influence on the decision to select the architectural agency as a partner, reflecting the generally high importance of geographical and social proximity for these collaborations to make up for the low cognitive proximity. In many cases, these projects evolve in iterations of face-to-face interactions where partners frequently meet to work together on the project. Thus, it is problematic if geographical proximity is absent. This is exemplified by the case of a water treatment firm who initiated a project with a technology developer from a different part of Denmark. While the lack of co-location was a serious concern prior to the project start, as it prevented spontaneous project meetings, the partners knew each other very well and decided to attempt to create an *"everyday atmosphere"* through frequent communication and monthly seminars. Still, this failed to provide the type of interaction needed by the water treatment firm, who therefore considers selecting a different partner in the next project.

The organisational proximity in the partnerships seeking to bring complementary technologies together is usually low as the requested type of knowledge is most often very different, making it unlikely to find it in another part of the firm. Regarding the institutional dimension, institutional proximity appears to be a way of overcoming differences in cognitive proximity, similar to the geographical and social dimensions. Most partnerships are characterised by intermediate or high levels of proximity. Thus, in situations where the needed competences are likely to be found in universities, firms seek out the research groups with a reputation for having an interest in relating their research to the real world. Interestingly, in cases with significant institutional differences between the partners, firms often work strategically with mitigating cultural differences through social activities. These practices often prove to be of significant value. As described by the R&D Manager of an energy efficiency firm concerning collaboration with a machinery producer: *"In a project like this, we need the team members to be in contact all the time... [S]o we have worked very consciously with levelling the cultural differences and that proved to be vital for reaching the goal."*

Approaching the motive of *assessing complementary technologies* from an economist's point of view, it is in essence an issue of joint production effects, where the low organisational proximity reflects the division of labour. The division is along functional (rather than quantitative) lines, resulting in a low cognitive proximity. This necessitates high geographical, institutional and social proximity in order to reduce the transaction costs in these collaborations.

4.2. Influencing market structure

In more than a third of the partnerships, a main objective was to influence market structure. Generally, these projects involve product development projects where the partner is chosen (partly) for strategic reasons, e.g. entering new markets or attaching third parties closer to the firm as a way of strengthening the position vis-à-vis competitors. Further, it is beneficial to distinguish between the aims of accessing new geographical markets and entering new business areas. While the organisational proximity is low in both cases, there are some differences along the other dimensions.

In a considerable number of the product development projects, firms specifically search for partners in countries where they wish to enter the market in order to gain access to the local knowledge, networks and reputation of the partners. Such collaborations are, by definition, between partners that are geographically distant, but the interviews show that they are typically also characterised by low social and institutional proximity. The interviews suggest that the institutional distance both reflects the geographical distance between the partners and is a desired feature, as the firms select partners that know and understand the local business culture. The large social distance is possibly linked to the empirical focus of the paper (product development projects). In these cases, the actual projects are to some extent excuses for getting to know the partner. Had they already known each other well, it would probably not have been necessary to link the aim of market access to a product development project. Nevertheless, the combination of low geographical, institutional and social proximity implies that these partnerships are risky and some of them do indeed go very wrong. However, the firms are aware of this and the risks they take are most often calculated. One way the firms seek to reduce the uncertainty is by selecting partners that are very similar to themselves along the cognitive dimension. A Senior Developer of an energy efficiency firm describes that his team started a project with *"the French version of [name of his own firm]"* in order to get access to EDF, the French utility provider. Another way of dealing with uncertainty is to adjust expectations. A CTO of a bio-energy firm describes the reason for initiating a partnership with a leading university in an emerging economy as *"purely a matter of branding"* where the expected input to the concrete product development was very low, primarily due to significant cultural differences.

In the cases where firms form partnerships in order to enter new business areas, the collaborations are typically between geographically close partners. The cognitive distance is often at an intermediate level as firms seek partners within related, but not similar, fields. Interestingly, most partners are far apart along the social and institutional dimensions in these collaborations. While, again, the empirical focus might affect the social dimension, the large institutional distance appears to be related to, firstly, differences in business sectors and, secondly, variation in size. In these types of partnerships, the initiating firm is often an SME seeking collaboration with a larger firm that will contribute to legitimatising the use of a technology or product in a new context. An example is a partnership between an energy efficiency firm and a large engineering consultancy which applied a product previously used for industrial buildings to residential housing. While the geographical distance between the partners is limited, the lack of institutional and social proximity as well as the size difference implies that these partnerships also have relatively high risks. Again, the firms seek to reduce the risks by promoting trust and minimising the incentive of the collaborator to break the agreement. This is illustrated by the quote of a Product Manager of an energy efficiency firm describing a partnership with a producer of agricultural equipment: *"These kinds of projects are always risky... [W]e do a lot of things for them that we don't do in other cases... [W]e invest in building trust."*

From an economist's perspective, *influencing market structure* is fundamentally a question of market access. The process of entering new geographical markets or business areas is associated with high costs which can be reduced significantly through partnerships with firms familiar to the specific context (Makino and Delios, 1996). In the case of foreign markets, the partners are typically locally based firms, working within the same industry, thus, low geographical and high cognitive proximity. For new business areas, firms seek partners within related industries in their home market, thus, intermediate cognitive and high geographical proximity. The institutional proximity is low in both types of partnerships due to – in the first case – the physical distance, and – in the second case – the combination of differences in business sectors and variation in size, as the initiating firm is often an SME seeking collaboration with a larger firm.

4.3. Obtaining knowledge

Nearly 30 % of the partnerships were initiated with the aim of obtaining knowledge. As with the motive of influencing market structure, the aim of this type of collaboration is at least partly unrelated to the actual product development project: the partner is selected on the basis of the expectation that the firm will gain access to knowledge through the collaboration. Therefore, firms most often seek out universities and research institutes in these types of projects, as new knowledge creation is concentrated here. It follows from this that few of these partnerships are between firms with a high organisational proximity. Furthermore, the institutional proximity between the partners is generally low in these projects, as both the incentive structures and the work routines differ considerably between firms and universities. The firms are most often aware that such differences make the collaborations resource demanding, but several interview persons stress that they consider the cultural variation an asset in the partner selection process for this type of collaborations. As described by an R&D Director of a firm from the automotive industry regarding university collaboration: *"We need to have different approaches. We are not interested in them becoming too focused on commercial aspects, because then they don't do their job properly... [I]t is up to us to evaluate if the extra thoroughness pays off."* Similarly, the Technology Director of a bioenergy firm notes that *"[W]e deliberately tap into knowledge from milieux that are culturally different from ours."*

A further feature of these partnerships is that they are often based on long-term relations with, e.g. former professors or co-students. Firms select partners with whom they have established a common communication code, thus, the social proximity is high and it is not uncommon that partners have collaborated over decades. While the interview persons stress that the personal relations are crucial in the cases where geographical proximity is absent, the majority of the collaborations are between partners separated by a limited distance. Therefore, even though geographical proximity is not as indispensible, as in the projects concerning complementary technologies, it appears to be facilitating these types of collaborations as well. A CTO of a water filtration firm describes how collaborations with two Danish universities progressed in very different ways due to the variation in physical distance to them. The informal character of the social relations, which were developed with the researchers at the nearby university, was a main reason explaining the larger amount of knowledge that was obtained from this partner and the subsequent selection of this university as a collaborator in a follow-up project. In this way, while knowledge can be obtained from distant partners, the social underpinning of such knowledge flows has a distinct geographical dimension.

Concerning the cognitive dimension, the firms select partners with an intermediate level of proximity. Contrary to collaborations where the motive is merely to access complementary technologies, in these cases the firms seek to actually obtain the knowledge. Thus, a main objective is generally to stay up-to-date with recent developments within a field of knowledge that is related to the firms' key competences. Illustrating this, a CEO of a bioenergy firm explains that in this sector it is important to possess knowledge within multiple scientific areas, and that the firm is strategically forming links to various universities to learn about current developments within different fields.

Finally, it should be stressed that firms consider the presence of a strong research centre an indispensible asset. In fact, the absence of such a partner may stimulate collective action among competitors promoting the development of one. This was the case within a renewable energy subsector, where all the Danish firms agreed to focus on a single research group at a university, in order to promote it as a centre for this specific type of technology. The firms decided to always include this group in funding applications and this strategy has indeed been successful, as the research group is now a valuable knowledge hub for this technology. This exemplifies how the business sector's need for knowledge flows may also benefit the universities.

Returning to the economist's point of view, collaborations with the aim of *obtaining knowledge* resemble user-producer relations (Lundvall, 1992) in the specific case of science. While it is in general expensive to leave user-producer relationships due to the costs of developing a mode of interaction that transfers knowledge efficiently, it is in particular the case with university-industry relations, as the actors operate within two distinct institutional spheres with great cultural differences (Dasgupta and David, 1994). Thus, social proximity is high in these partnerships where, furthermore, some cognitive overlap is critical for the ability of the users to obtain the knowledge.

4.4 Reducing innovation time-span

The speed of commercialisation is often the decisive factor between commercial success and failure. Therefore, firms often establish partnerships with the intention of reducing the innovation time-span. These collaborations are more often characterised by a high organisational proximity than the three previously described types, as firms often turn towards subsidiaries and associated companies in situations where the development of a new product is under considerable time pressure. This is exemplified by a producer of wind turbine components, who established a project across several divisions in order to keep up with the continuously increasing size of wind turbines. While fast up-scaling of components offers commercial possibilities for suppliers, it is also a process that is indispensible for the long run existence of these firms. Therefore, collaborative efforts across divisions are often established in such situations.

In cases where intra-firm partnerships are not possible, firms preferably rely on well-known partners. However, as the pace of the projects is a crucial selection parameter, firms are unwilling to, e.g. postpone projects in order to secure the participation of a preferred partner and, thus, they often have to settle with partners where the social proximity is relatively low. In these cases, firms use their networks to identify potential partners. The firms generally select partners located within close distance, as the projects are characterised by intense interaction over a limited time period. Further, they seek partnerships with high cognitive proximity as there is no time to overcome large cognitive differences. The firms are aware that this has a negative effect on the ability to create path breaking solutions, but this is not what they seek in these types of projects. This strategic prioritisation is illustrated by the founder of a bioenergy firm concerning such a partnership: *"It is an advantage that we share the same frame of reference, but it is a weakness that we don't get inputs from other directions... [H]owever, the set-up was appropriate in this concrete project."* Notably, the firm selected a partner with a different cognitive framework for a project where the main motive was influencing the market structure.

While the institutional proximity is on average high in these partnerships, there are also a considerable number of cases where the cultural differences are substantial. In these collaborations, the firms often select a partner that can be responsible for the more simple parts of the product development in order to provide sufficient time for themselves to focus on the more complicated issues. Typically, firms with a concentration of highly skilled workers will collaborate with partners with a majority of semi-skilled workers in such projects. However, the firms will most often make sure that the partner has at least a small R&D department to ease communication in the project. Reflecting this, a Technical Manager of a green construction firm explains that they selected a partner from the metal plating industry who had some engineers employed in development positions, so that the work routines would not be too different between the two firms.

Reducing innovation time-span is essentially a mean to secure temporary monopoly positions which allow firms to extract innovation rents (von Hippel, 1988). When such rents are within reach, firms may seek access to complementary resources in order to secure first mover advantages. The organisational proximity is high, as firms prefer not to share the innovation rents with other actors. However, when intra-firm partnerships are not possible, firms favour collaborations with high cognitive, institutional and geographical proximity in order to expedite the development.

4.5. Sharing costs and risks

Even though the cleantech industry has been less affected than many other sectors by the increasingly difficult access to capital as a result of the financial crisis, firms sometimes still need to share the costs and risks associated with product development processes. In these cases, firms often engage in collaborations with partners located in areas with significantly lower labour costs. While the geographical proximity is low in these partnerships, both the organisational and social proximity is generally high. In many cases, firms seek out partners from the same company located overseas in order to minimise the risks associated with acting in a very different institutional environment. However, the combination of high organisational and low institutional proximity also presents challenges to the firms. As the CTO of a bioenergy company explains on an intra-firm partnership with an Asian division with a very different work culture: *"The agreements are verbal... [B]asic issues as IPR ownership or payment of salaries are most often not written down [...] as they are in the contracts we have with suppliers out there. But these [intra-firm] agreements are in the grey zone, unfortunately."*

The quote highlights the difficulties of overcoming cultural differences, even in intra-firm partnerships. However, this seems to surprise few of the firms and most of them take precautions before entering into such partnerships by, e.g. providing key employees with cultural training as well as reserving sufficient resources at the headquarter to follow the process closely and have frequent meetings with representatives from the partner. A supplier of components to bioenergy plants applied a more radical solution when cultural differences hampered collaboration with a newly acquired division in Eastern Europe: the entire management level was fired and replaced with people expected to have a more Western European management style.

Regardless of the means applied, the examples highlight that considerable resources have to be invested to make these collaborations work, hence, the potential savings on labour costs must be large to make the partnerships meaningful. However, a second type of costs and risks sharing collaborations are not driven by differences in labour costs, but rather by initiation of unusually complicated and capital demanding development projects. While the cognitive proximity is generally at an intermediate level in the labour costs driven collaborations, as the partners often work in similar industries, but at different developmental stages, the collaborators have a high cognitive proximity in this second type of partnerships. Furthermore, firms select partners that they know and trust, as the collaborations usually involve a significant amount of knowledge sharing. However, as these collaborations are often of large importance for the future development of the firms, this socially based trust is complemented by other measures. This is exemplified by an energy efficiency firm that shares all the know-how and all the drawings concerning a specific product with the partner in a project of this kind, but it keeps the codes to the embedded software, which considerably reduces the risk of opportunistic behaviour.

The motive of *sharing costs and risks* is driven by labour cost differences and scale economies. Collaborating with partners in areas where labour costs are considerably lower can reduce development costs significantly; however, these partnerships are characterised by a low institutional proximity which makes the collaborations difficult. If possible, firms reduce transaction costs by selecting partners with high organisational and social proximity. In the case of complicated and capital demanding projects, small firms that do not have the capacity to internalise the scale economies will seek to establish collaborations with partners similar to themselves.

4.6. SUMMARY

The findings of the analysis are synthesised in table 2. To recapitulate, geographical proximity is found to be of great importance in three out of the five types of product development projects. In projects with the aim of *assessing complementary technologies*, geographical proximity is important in facilitating social proximity and thereby trust. Further, the functional effect of geographical proximity in allowing easy face-to-face interaction is also central. In partnerships with the objective of *obtaining knowledge*, it is in particular the close relation between geographical and social proximity which plays a key role. As the intensity of interaction is generally lower than in the previous type of collaborations, the ability to meet without difficulty due to physical proximity is less important. In contrast, this effect of geographical proximity is vital for partnerships with a focus on *reducing innovation time-span* because of the need for intense interaction. Further, with the speed of development being a priority, geographical proximity also has a role in facilitating institutional proximity which allows swift and easy collaboration. In summary, geographical proximity is crucial in facilitating collaborations with these aims through different forms of geographical effects.

In the remaining two types of partnerships, geographical proximity plays a less prominent role. Geographical proximity is low in the majority of collaborations focused on *influencing market structure*, as firms often seek entrance to foreign markets. Most partnerships with the aim of *sharing costs and risks* are also characterised by low geographical proximity, as this type of proximity is rendered superfluous by the organisational proximity that enables collaboration. Thus, summarising, the analysis highlights the importance of geographical proximity in collaboration projects at the core of innovation processes – assessing technologies, obtaining knowledge and reducing innovation time-span. Conversely, geographical proximity may in fact be undesirable in projects with a more indirect relation to innovation processes. In this way, the analysis indicates that firms rely on geographical proximity in the most innovative aspects of their work, while geographically distant relations are formed to enter new markets and benefit from cost advantages.

Table 2. Overview – characteristics of proximity dimensions in different types of innovation projects

	Assessing complementary technologies	Influencing market structure	Obtaining knowledge	Reducing innovation time-span	Sharing costs and risks
Social proximity	High Partners whom the firm knows and trusts	Low to medium Primarily newly established partnerships	High Often based on long-term relations with, e.g. former professors or co-students	Varying Firms preferably rely on well-known partners, but must often settle with unknown alternatives	Medium to high Often partners from the same company or well-known suppliers
Institutional proximity	Medium to high Initiatives have often been taken to mitigate differences if they exist	Low Partners that know and understand the local business culture	Low Often universities or research institutes	Varying, but primarily high Most often firms with similar cultures	Low Generally firms operating in a very different cultural context
Organisational proximity	Low Needed competences not available in the firm	Low Partners in markets where the firm is not represented	Low Knowledge unavailable inside firm	Varying 1) Either other divisions… 2) …or external partners	High Often partners from the same company located overseas
Cognitive proximity	Low Different technological discipline	Medium to high Firms working within similar or related industries	Medium Related technological discipline with some cognitive overlap needed	High Similar or related disciplines, no time for overcoming large cognitive differences	Varying Often partners within similar industries, but frequently at a different developmental stage
Geographical proximity	High Necessary to make up for low cognitive proximity. Frequent interaction	Varying, but primarily low 1) Firms located in new markets 2) Often national partners when focus is on entering new business areas	Varying, but primarily high Often high geographical proximity to facilitate social proximity	High Need for frequent interaction	Low Often firms located in parts of the world where labour costs are much lower

5. CONCLUSION

The perspective on collaboration processes which is applied in this study combines the *"why"* and the *"how"* questions (Gulati, 1998, p. 414). It is argued that collaboration motives have a profound influence on the partner selection process and the resulting partnership characteristics concerning the degree of proximity along the spatial and non-spatial dimensions. Focusing on the causes for variation in proximity between different types of collaborations highlights how the proximity framework can be employed in a dynamic way. Rather than searching for an optimal level of proximity or determining whether or not a certain type of proximity facilitates partnership formation, the paper stresses the importance of recognising the heterogeneity of the partnerships and the reasons for this variation. This leads to the insight that firms specifically select nearby partners (in both spatial and non-spatial terms) in some situations, while distant partners are preferred under other circumstances. In this way, they are juggling with distance and proximity.

The empirical analysis of collaborations around product development projects in the Danish cleantech industry emphasises the value of having access to a diverse portfolio of potential partners. This is exemplified by the cognitive dimension, where the analysis illustrates that there is not an optimal cognitive distance (Nooteboom, 1999) between partners, for a given firm at a given point in time. When firms seek partners that can bring complementary technologies into a project, they search for cognitive differences. While such collaborations are difficult and costly, they are nevertheless often necessary to develop a specific product. In partnerships where a main objective is to obtain knowledge, firms prefer partners with an intermediate level of cognitive distance. In these cases, the firms need to obtain the knowledge; hence, the differences must not be too large between the collaborators. Finally, in projects where the objective is to reduce the innovation time-span, firms select partners with a high cognitive proximity. These partnerships are less inspiring and stimulating than those with a lower cognitive proximity, but speed is the main priority in these collaborations. Thus, firms seek partners where they do not need to spend time and resources on overcoming cognitive differences.

Turning to the geographical dimension, the analysis stresses that geographical proximity is crucial in three out of the five types of collaborations. Theoretically, it is possible to substitute non-spatial proximity for geographical proximity in cases where the need for frequent face-to-face interaction is low. However, in reality, the importance of the facilitating effect of geography on social and institutional proximity implies that geographical proximity is rarely absent in these types of collaborations. This has important consequences for the debate in economic geography on global pipelines (Bathelt et al., 2004). The analysis presented in this paper suggests that global pipelines play a minor role in collaborations with the aim of assessing complementary technologies or obtaining knowledge, where it is the partner's technological competences that are the main selection criterion. In this way, geographical proximity is highly important in collaboration projects at the core of innovation processes. Still, global pipelines appear to be important when the collaborative knowledge production is less sophisticated or when the collaboration projects are motivated by market access or cost considerations. This is a very different view on the role of global pipelines compared to the work of Moodysson (2008), where global pipelines are found to play a central role in different forms of interactive knowledge creation. However, Moodysson studies the life science industry, which is generally characterised by a higher reliance on global linkages than most other industries (Martin and Moodysson, 2012). In contrast, the conclusions of the analysis presented in this paper warn against understating the importance of geographical proximity for collaboration projects, in particular those directly related to innovation processes.

The findings of this study have important implications for the analysis of central themes in economic geography, beyond partnership formation, such as the location choices of firms. Research shows that single plant and multi-plant location choices differ (Mota and Brandão, 2011), but little is known concerning the causes of this variation. Applying an analytical framework that focuses on how motives shape firm decision-making processes will highlight how the location choices of multi-plant firms depend on the type of proximity (to knowledge sources, new markets, other subsidiaries etc.) they seek to achieve. Further, it will also emphasise how single plant firms, which do not have the opportunity to establish a division in a specific advantageous location, can compensate for the lack of organisational proximity through other forms of proximity.

Finally, acknowledging the limitations of this paper points towards a number of future research questions. First, as this paper has focused on partnership formation, the question of partnership performance remains. It is not certain that the preferred characteristics of partners, according to the collaboration motives, actually deliver the best results. Naturally, such an analysis would need to take the partnerships' different objectives into account when selecting the performance variables. Second, partnerships are frequently established with more than one objective in mind. While there will often be a main motive that will shape the search criteria, little is still known of the interaction effect between different motives on partnership formation. Third, this paper has highlighted the influence of different types of motives, but other factors may contribute to the heterogeneity in proximity, such as innovation radicality (Hoetker, 2005; Li et al., 2008) and commercial importance. One could for instance speculate that firms prioritise a high social proximity in crucial projects, while new partners are tested in less important projects. Identifying and examining such factors are important to improve the understanding of the causes of proximity variation in collaborations between actors.

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PAPER III

Cross-border innovation – regional integration in the Øresund Region 1994-2009

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Abstract

The topics of regional innovation systems (RIS) and cross-border regions attract increasing attention, but few studies combine the themes. Further, the existing empirical studies of cross-border innovation analyse one case at one point in time, thus, making it difficult to assess the progress of integration in the regions, as well as the effect of cross-border innovation policies.

Consequently, important questions are left unanswered. Does the removal of barriers to interaction directly impact collaboration activity in cross-border regions? Are there differences between the impact on the quantity and the quality in the cross-border knowledge creation processes? And is there an effect on extra-regional knowledge linkages?

This paper contributes to uncovering these questions by analysing regional integration in the Øresund Region over time. The paper focuses on a specific part of the RIS, namely the biotech industry. Research collaboration between actors from the Danish and Swedish sides is analysed. Scientific collaboration constitutes an important element of a RIS, particularly in research intensive sectors. The quantity and quality of co-authorships are used as indicators for research collaboration. The results indicate that the removal of internal barriers in a cross-border region can have a substantial and long-term positive effect on knowledge flows if a targeted policy effort is made. In the absence of such policies, no effect is found. Further, the study suggests that cross-border integration may indeed affect the linkages to other regions.

Keywords

Cross-border innovation, cross-border regions, biotech, co-authorships, collaboration, Øresund Region

1. Introduction

Borders between countries continue to impact economic development in today's globalised world. Therefore, different fields within the social sciences have increasingly given attention to the influence of *"the lines that continue to separate us"* (Newman, 2006, p. 143). In economic geography, this literature has also been associated with the rise of regional studies and the insight that economic progress must be founded on local characteristics, competences and institutions (Storper, 1997). However, as functional regions do not always follow the borders of national states, one specific topic of interest has been the integration of cross-border regions – defined as regions that continuously span over at least one national boundary – such as the Øresund Region (Denmark/Sweden), the Centrope area (Austria/Czech Republic/Hungary/Slovakia) and Euregio (Netherlands/Germany). These integration processes are at the same time necessary and valuable; necessary as regions with fragmented economies have few chances of prospering in a highly competitive global economy, and valuable as the differences in development trajectories between neighbouring areas in separate countries can lead to complementarities and productive interactions. Naturally, such variations in culture, technological specialisation, institutions etc. are at the same time challenges which often act as barriers to cross-border integration.

Following the rise in the number of cross-border partnerships (Perkmann, 2003), several studies have analysed cases of regional integration in cross-border regions within the last ten years (see e.g. Bucken-Knapp, 2001; Matthiessen, 2004; Bygvrå and Westlund, 2005 for examples from the Øresund Region). However, most analyses focus on issues such as commuting and shopping behaviour, and few studies deal with the creation of common innovation and knowledge spaces (exceptions are Hassink and Dankbaar, 1995; Koschatzky, 2000; Coenen et al., 2004; Hansen and Hansen, 2006). Recently, theories on the formation of cross-border innovation systems have been proposed, drawing on the insights from the regional innovation systems (RIS) approach (Trippl, 2010; Lundquist and Trippl, 2011).

The process of developing a cross-border region, from a low to a high level of integration, rarely progresses in a linear way. Some periods are characterised by rapid integration due to the elimination of barriers, e.g. political, such as the effect of the fall of the iron curtain on the Centrope Region, or physical, as in the case of the impact of the fixed link between the Danish and Swedish parts of the Øresund Region (Lundquist and Trippl, 2009). Despite the presumed considerable importance of such events, their effect on the creation of cross-border knowledge spaces is still more or less a black box and a number of key questions need to be addressed. It is unknown if the sudden removal of significant barriers directly impacts collaboration activity in cross-border regions. Likewise, the literature has yet to distinguish between the effect on the quantity and the quality in the cross-border knowledge creation processes. An additional question is the effect of cross-border integration processes on the extra-regional knowledge linkages – do they become less important as a cross-border RIS develops, or is it more a plus-sum than a zero-sum game?

This paper aims to contribute to uncovering these questions by analysing the regional integration of the Øresund Region in the period 1994-2009. The paper deals with a specific part of the RIS, namely the biotech industry in the region. Research collaboration between actors from the Danish and Swedish sides is analysed. Scientific collaboration constitutes an important element of a RIS, particularly in research intensive sectors such as biotech. The quantity and quality of co-authorships is used as an indicator for research collaboration.

The point of departure is the theory of RIS, which is discussed in the following section. The third section reviews previous work on cross-border regions with a focus on the creation of integrated innovation systems. Section four briefly presents the Øresund Region, while the fifth part of the paper describes the applied methodology. Section six presents the analysis. The seventh and final section concludes and discusses the findings.

2. Regional innovation systems and knowledge creation

The development towards a learning economy has been fuelled by an increasing speed in knowledge diffusion, and a key characteristic is the rising long-term knowledge intensity of the economy (Amin and Cohendet, 2004). Acquisition, creation and utilisation of knowledge shape economic growth. A key insight from the last decades work within the social sciences is that external knowledge linkages are of increasing significance in the learning economy, as vertical disintegration becomes a widespread phenomenon. Links to customers and suppliers are crucial in both high- and low-tech industries in order to obtain market knowledge and feedback (Kline and Rosenberg, 1986; von Hippel, 1988; Hansen and Serin, 1999).

A focus on the importance of localised institutions for knowledge production and innovative collaborations has been associated with this development (Dosi et al., 1988). This has in particular been emphasised in the literature on regional innovation systems which stresses the systemic nature of innovation processes as well as the importance of agglomeration economies. Thus, a system of innovation is defined as (Edquist, 1997, p. 14): *"[…] all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations."*

The RIS approach stresses the importance of the regional context for the functioning of innovation systems. According to Cooke (2001), many regions now have the resources and authority to promote their own regional agendas within areas such as research and development (R&D). Thus, there is a strong case for focusing on the regional meso level, which covers areas united by common institutions and a shared culture. Still, Cooke (2004a) notes that the internal functioning of the RIS should be seen in relation to actors operating in other regions or at different scales. By including these aspects of knowledge production in the framework, Cooke responds to the critique of among others Bunnell and Coe (2001) and Amin and Cohendet (2004) who highlight the importance of other scales than the local and regional for the creation of knowledge. Yet, it also adds some ambiguity to the RIS framework. While it maintains the prominence given to the regional scale, it opens up for discussions of the general applicability of the theoretical framework – when is the regional context sufficiently important for an innovation system to justify the RIS label?

The work on local buzz and global pipelines seeks in a similar way to encompass both local and global knowledge linkages in one theoretical framework by emphasising both the significance of agglomeration economies and distanciated knowledge links (Bathelt et al., 2004). Local and global flows of knowledge must be balanced in order to avoid technological lock-in for a region, while still allowing the exploitation of agglomeration advantages. Again, this raises the question of variation in the intensity of local and global knowledge linkages according to, e.g. industry characteristics.

One way of differentiating between innovation patterns in industries is by considering differences in their knowledge bases (Asheim and Gertler, 2005; Asheim, 2007). The literature distinguishes between analytical, synthetic and symbolic knowledge bases, which are characterised by differences in research intensity, the importance of codified and tacit knowledge as well as the balance between radical and incremental innovations. Most firms in general – and the most innovative firms in particular (Jensen et al., 2007) – combine the ideal types of knowledge bases, but a main knowledge base can be assigned to the majority of industries.

A key characteristic of the *analytical knowledge base* is the use of scientific methods and modelling. Codified knowledge is both a major input and output of the knowledge creation process, implying that links to universities and research institutions are crucial to the innovativeness of firms with analytical knowledge bases. Innovations are often radical, contrary to the innovations of firms with *synthetic knowledge bases* which are predominantly incremental. These firms primarily utilise existing knowledge in the development of new products and processes, and tacit knowledge acquired through learning by doing and learning by using is therefore central to innovation processes. While links to knowledge institutions can be of importance in some instances, up- and down-stream relations are of greater significance as innovation projects often revolve around solutions to customer specific problems. Finally, the *symbolic knowledge base* is predominant in industries where the value creation is associated with the production of immaterial characteristics – e.g. ideas, images and symbols. Networking, creativity and social skills are more relevant than formal education and certified qualifications for such firms, as the knowledge creation process is often very context dependent. Innovations depend on tacit knowledge concerning the everyday habits and norms of certain groups, and the projects are often carried out in intense collaborations of limited duration with external partners (Asheim, 2007).

Considering that research suggests that international and global knowledge linkages are of greater significance than national and regional partnerships within science and R&D (Cooke and Wills, 1999; Hilpert, 2006), it can be expected that firms from research intensive industries with an analytical knowledge base are primarily depending on global knowledge linkages. Work by Coenen et al. (2004), Gertler and Levitte (2005) and Moodysson (2008) on the biotech industry confirms this expectation and, in a recent interesting paper, Martin and Moodysson (2012) carry out a comparative study of the knowledge networks of industries with different knowledge bases from the same region. They find that global networks are particularly important for firms in the life science industry (analytical knowledge base), while the food industry (synthetic knowledge base) primarily sources knowledge from nationally and regionally configured networks. Lastly, they find that knowledge creation in the moving media industry (symbolic knowledge base) depends on highly localised networks, where the partners share a context specific knowledge on the local environment.

3. Cross-border regions

The results of the study by Martin and Moodysson (2012) suggest that the integration of cross-border regions might be of primary importance to industries with synthetic and symbolic knowledge bases, considering the global nature of knowledge linkages in industries with analytical knowledge bases such as biotech, IT and nanotech. However, this question and many others concerning the creation bi-national innovation spaces has so far remained untouched by the scientific literature on cross-border regions. A main topic in border studies is the relationship of these regions *vis-à-vis* their national states (Anderson and O'Dowd, 1999; García-Álvarez and Trillo-Santamaría, 2011). On the one hand, some authors stress the increasing influence of national government on cross-border partnerships (Church and Reid, 1999), and the ability of central state authorities to prevent the initiation of cross-border cooperation (Perkmann, 2003). On the other hand, Johnson (2009) notes the ways in which regional elites use the cross-border integration policies encouraged by the European Union to promote specific economic development goals, which are often detached from the agenda of the central government. Despite these differences, there is widespread agreement that funding opportunities are crucial in many cases for the commitment to regional integration processes. Many cross-border partnerships are in reality *"grant coalitions"* (Church and Reid, 1999, p. 645), leading Paasi (2002, p. 200) to conclude that today these areas are mainly *"regions on paper"*. While this is undoubtedly the case in quite a number of regions, such statements highlight the importance of measuring real integration beyond cooperation in government sponsored programmes. Approaches to measuring these integration processes include analysing developments in transportation flows (Matthiessen, 2004; Knowles and Matthiessen, 2009), labour market dynamics (Van Houtum and Van Der Velde, 2004; Schmidt, 2005) and shopping behaviour (Bygvrå and Westlund, 2005; Asplund et al., 2007).

However, only a small number of cross-border integration studies deal with issues related to innovation. Coenen et al. (2004) and Moodysson and Jonsson (2007) both show that global linkages are of greater importance than local collaborations for innovation projects in biotech firms located in the Øresund Region. Hassink and Dankbaar (1995) find that cross-border interaction is of little importance for innovation processes in the Euregio Mass-Rhine, and Koschatzky (2000) reaches a similar result in the case of Alsace and Baden. Finally, Leick (2011) finds that cost reduction and revenue increase are the primary positive outcomes of co-operation between German and Czech firms from Saxony and North Bohemia, while knowledge production is of little importance.

Yet, these studies all analyse one case at one point in time, thus, making it difficult to assess the progress of integration in the cross-border regions. Exceptions to this pattern are studies by Hansen and Hansen (2006) and Krätke and Borst (2007). The findings of Hansen and Hansen (2006) indicate a growing integration in the years 1994 to 2005 in the Øresund Region within the scientific community. Krätke and Borst (2007) show that German-Polish integration primarily takes place between West German metropolitan regions and Polish regional economic centres, thereby overlooking the border regions, even though East Germany appears to be catching up.

Apart from these few studies, work on cross-border innovation systems has so far been limited to theoretical contributions. Drawing on insights from the RIS approach, Trippl (2010) describes five central dimensions in the creation of transboundary knowledge spaces: knowledge infrastructure, business characteristics, nature of relations, socio-institutional characteristics and governance. Lundquist and Trippl (2011) introduce a typology of cross-border innovation systems based on these five parameters as well as accessibility. The *weakly integrated system* is characterised by limited cross-border interaction and the relations which exist result from cost asymmetries. This situation might be due to a lack of synergies if the economic structure and specialisation between the various parts of the region are either too similar or too different to gain from an intensified relationship. However, it can also result from significant barriers which hinder exploitation of synergies. Naturally, accessibility can be one such barrier, but differences in, e.g. legislation and culture are other factors which may inhibit integration.

In the *semi-integrated system*, cross-border innovation networks are developed in some fields, but not throughout the innovation system. Travelling between the different parts of the region is not too costly and time consuming, thus, allowing frequent interactions. The integration process is supported by specialised organisations, and there is a general awareness in the region towards the possibilities offered by cross-border cooperation. Still, common innovation collaborations are not central to the competitiveness of the cross-border region. This is the case in the *strongly integrated system* – the cross-border RIS – where economic activity in the region is fully integrated. Knowledge flows are no longer confined to a few industries and no significant barriers to interaction remain. Lundquist and Trippl (2011, p. 9) characterise this last stage as *"the 'utopia' of cross-border region building"*, but note that it may be important in the development of visions for cross-border innovation systems.

4. The Øresund Region

The Øresund Region is constituted by the eastern part of Denmark and the southern part of Sweden. While the two urban areas of Copenhagen and Malmö-Lund make up the core of the region, the formal definition also includes the rest of Scania on the Swedish side and the whole of Zealand as well as the islands of Bornholm, Lolland, Falster and Møn on the Danish side. The level of interaction in the region was very low before the opening in 2000 of the fixed link across the strait separating the two countries (Matthiessen, 2004). Post-bridge rail and vehicle traffic was initially below forecasts, but it increased significantly from 2004, and traffic has now exceeded pre-bridge expectations (Knowles and Matthiessen, 2009). A new group of 'regionauts', consisting of citizens utilising the possibilities offered on each side of the strait in their everyday life, contribute to the transformation of the region (Löfgren, 2008).

Thus, the construction of the fixed link has radically changed the conditions for creating a cross-border RIS. While the region could previously be characterised as a *weakly integrated system*, mainly due to a lack of physical accessibility, it can now be considered as a *semi-integrated system*, where the biotech industry emerges as a pioneer industry in terms of cross-border integration (Lundquist and Trippl, 2009). The continuing presence of administrative and cultural barriers (Knowles and Matthiessen, 2009) are important reasons preventing the creation of a *strongly integrated system*, but it is of specific relevance for our analysis to note the variance in the economic structure between the two parts of the region. There are significant differences between the Danish and Swedish national innovation systems and the way they react to the challenges presented by economic globalisation (Edquist and Lundvall, 1993; Benner, 2003). Thus, the fact that the region contains two different socio-economic trajectories poses an important challenge for the creation of a fully integrated RIS (Lundquist and Winther, 2006).

5. Methodology

The difficulty of accessing data is probably a main reason for the lack of studies on cross-border RIS. While it is generally complicated to retrieve information on knowledge flows, it is even more difficult when the linkages cross national borders. In this study, the object of analysis is co-publications between scientists in universities, firms and NGOs from the Swedish and Danish parts of the Øresund Region, with a particular emphasis on progress in integration within the field of biotech.[1] Thus, the focus is on the 'knowledge infrastructure' dimension in Lundquist and Trippl's (2011) cross-border innovation system framework. The biotech industry is of considerable economic importance in the Øresund region (The Capital Region of Denmark, 2008), and policymakers have specifically focused on strengthening interaction among biotech firms as well as branding of the region as Medicon Valley within the last 15 years. Furthermore, the industry is chosen as it is characterised by a pronounced analytical knowledge base with an apparent high importance of global knowledge flows. This makes it interesting to analyse if a considerable policy effort can stimulate the development of intra-regional knowledge flows in an industry characterised by a great emphasis on global knowledge flows.

The quantity of co-authorships can be seen as a representation of the extent of scientific collaboration. Data on scientific publications is obtained from the Science Citation Index Expanded (SCIE) database available through ISI Web of Knowledge, where all contributions are provided with subject codes and full affiliations for all authors. Firstly, the number of co-authored papers across the Øresund is identified for each year in the period 1994 to 2009. Further, the number of citations in a two year window following publication is recorded as a proxy for the scientific quality of each paper. According to He et al. (2009), citations received in the first two years are a good predictor of the long-term number of citations. Furthermore, it is also the lag used by the ISI Web of Knowledge algorithm that calculates journal impact factors.

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[1] Following Sandström and Norgren (2003), biotech is defined as the following eleven disciplines: biochemistry and molecular biology, biomedical engineering, biophysics, biotech and applied microbiology, cell biology, genetics and heredity, immunology, medicinal chemistry, microbiology, neurosciences, and virology.

Secondly, the number of co-authorships between the Øresund Region and five biotech regions is also calculated for each year of the period in order to compare the development within the Øresund Region. This makes it possible to assess whether the observed development between the Danish and Swedish parts of the region is atypical or part of a general trend. The selected regions are Basel, Massachusetts, New Jersey/New York, Île-de-France and Stockholm. These city regions are considered among the 20 bioscience mega centres in the world, characterised by a concentration of large pharmaceutical firms' R&D laboratories, high-quality publicly funded biotech research centres and universities, a considerable presence of dedicated biotech firms, as well as sophisticated local suppliers (Cooke, 2004b; Zeller, 2010). The role of such regions of excellence for scientific co-publications is significant within biotech (Hoekman et al., 2009). Benchmarking the increase in co-authorships and citations between the Danish and Swedish parts of the Øresund Region, with the similar development between the Øresund Region and each of these areas, will give a clear indication on the progress of the cross-border integration, both in terms of quantity and quality.

The extent of collaboration with Stockholm is of particular interest, as it is located less than 500 kilometres from the Øresund Region. The city is a biotech node of significant importance, particularly due to the Karolinska Institute, a world leading public research organisation (Coenen et al., 2004). Thus, Stockholm has the status of the Øresund Region's 'neighbouring biotech centre', and it is therefore particularly interesting to examine if the integration process in the Øresund Region affects the interactions and knowledge flows with Stockholm.

6. Empirical findings

6.1. Within the Øresund Region

The number of co-authorships between Danish and Swedish researchers in the Øresund Region has increased considerably during the years 1994-2009. The growth has been quite constant throughout the four periods shown in table 1. Hence, collaboration across the strait was already intensifying before the actual opening of the fixed link in 2000. Further, the share of co-authorships represented by biotech publications has remained rather stable.

Table 1. Number of co-authorships between the Danish and Swedish parts of the Øresund Region

	1994-1997	1998-2001	2002-2005	2006-2009
All publications in SCIE	525	709	939	1282
Biotech publications	89	111	172	224
Biotech share	17.0 %	15.7 %	18.3 %	17.5 %

Source: Own calculations from ISI Web of Knowledge

Following the literature on innovation in the biotech industry (e.g. Liebeskind et al., 1996; McMillan et al., 2000), it is hardly surprising to observe that collaborations between public institutions are the most frequent within this sector (see table 2). However, while public-public co-authorships were very dominating in the first period, private firms and research institutes are increasingly engaged in cross-border collaboration. The private-private co-authorships are still few and far between, but the firms in the region are gradually becoming more involved in partnerships with public organisations from the other side. This is particularly the case for Danish firms, and one in five co-authorships is now between Danish private and Swedish public organisations.

Table 2. Share of biotech co-authorships according to type

	1994-1997	1998-2001	2002-2005	2006-2009
Danish public - Swedish public	87.7 %	80.1 %	73.2 %	71.7 %
Danish public - Swedish private	1.8 %	4.0 %	3.3 %	6.5 %
Danish private - Swedish public	9.6 %	14.6 %	20.1 %	19.9 %
Danish private - Swedish private	0.9 %	1.3 %	3.3 %	1.9 %
Total	100.0 %	100.0 %	100.0 %	100.0 %

Source: Own calculations from ISI Web of Knowledge

The fact that the majority of the Øresund Region's biotech firms are located on the Danish side partly explains the large participation of the Danish private sector in the cross-border collaboration. However, a second factor of significant importance is the very high standard of research facilities at the University of Lund. In particular, the university's Biomedical Centre is an attractive collaborating partner for Danish firms, which offers access to a global centre of excellence, particularly within stem cell research (Hansen and Hansen, 2006; Benneworth et al., 2009).

The importance of Lund University as a hub of biotech research in the region is confirmed by table 3, which lists the six most important public and the four most important private organisations in biotech cross-border co-authorships. Being involved in 427 co-authorships over the 16 years, Lund University has more than twice as many co-authorships as the University of Copenhagen which is second on the list. Overall, researchers from Lund University participate in 72 % of all the biotech co-authorships.

In terms of the private organisations, Novo Nordisk appears as a key actor with 31 co-authorships in addition to the 18 by Steno Diabetes Center, a private research hospital owned by Novo Nordisk. No private Swedish organisations appear on the list – the most active Swedish firm in cross-border co-authorships is AstraZeneca which participated in 8 publications throughout the period.

Table 3. Number of biotech co-authorships by key organisations

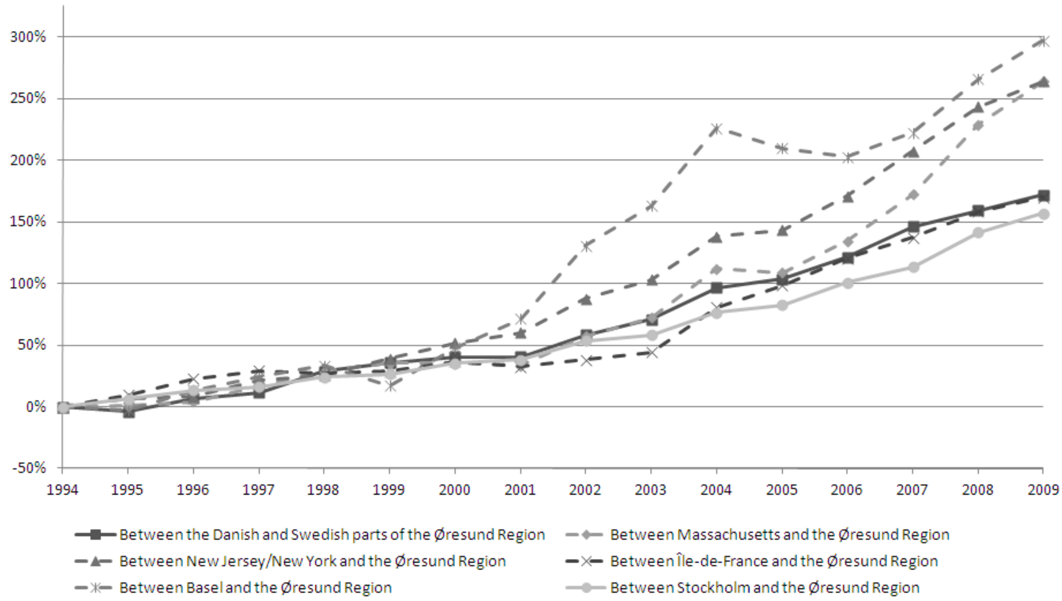
	1994-1997	1998-2001	2002-2005	2006-2009	Total
	Public				
Lund University (S)	57	76	121	173	427
University of Copenhagen (DK)	15	37	46	83	181
Copenhagen University Hospital (DK)	20	26	35	52	133
Lund University Hospital (S)	26	28	34	41	129
Statens Serum Institute (DK)	19	12	15	13	59
Technical University of Denmark (DK)	2	12	13	31	58
	Private				
Novo Nordisk A/S (DK)	4	11	3	13	31
Steno Diabetes Center A/S (DK)	1	0	2	15	18
NsGene A/S (DK)	0	3	7	6	16
The Danish Cancer Society (DK)	0	2	5	9	16

Source: Own calculations from ISI Web of Knowledge

6.2. International comparison

Although the results in the previous section indicate growing cross-border collaboration, these findings must be seen in the perspective of the general development in co-authorships due to two reasons. Firstly, the number of publications included in the database is not constant over time and, secondly, the increase in co-authorships in the Øresund Region might be part of an overall increase in the propensity of researchers to collaborate with partners outside of their local area. Scientific research collaboration has increased over the last decades and it is particularly a frequent phenomenon within interdisciplinary sciences such as biotech (Ponds et al., 2007). While an increase resulting from such a general growth in co-authorships does imply greater cross-border interaction, it does not point towards a real functional integration in the innovation system. Thus, to find indications of such a process, the development in co-authorships within the Øresund Region must be compared to the development of co-authorships with other regions.

Figure 1. Change in the total number of co-authorships in SCIE, 1994-2009

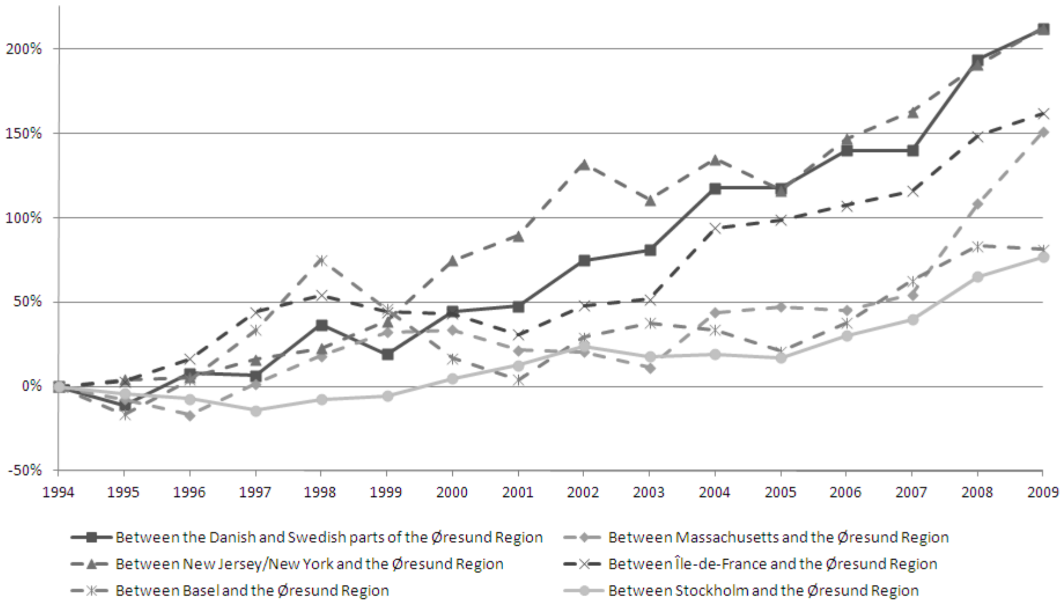


Note: To reduce fluctuations, values are calculated based on 3-year averages of the number of co-authorships in the preceding, the actual and the following year. Values for 1994 and 2009 are 2-year averages.

Source: Own calculations from ISI Web of Knowledge

Resulting from this line of analysis, figure 1 displays the development in co-authorships within all the disciplines included in SCIE. Clearly, little evidence for an increasing integration in the cross-border RIS can be found here. The largest increase is found in co-authorships with Basel, which is however also the region which the Øresund Region has the lowest amount of co-authorships with (see appendix table A1 for the absolute figures). Yet, the number of co-authorships with Massachusetts and New Jersey/New York has also grown faster than the development within the Øresund Region, particularly since the millennium, and the extent of partnerships with both of these regions is now substantial. The increase between the Danish and Swedish parts of the Øresund Region is comparable to the development with Île-de-France, and it is only the Øresund-Stockholm collaboration which has experienced a slightly smaller growth.

Figure 2. Change in the number of biotech co-authorships, 1994-2009



Note: To reduce fluctuations, values are calculated based on 3-year averages of the number of co-authorships in the preceding, the actual and the following year. Values for 1994 and 2009 are 2-year averages.

Source: Own calculations from ISI Web of Knowledge

Following the development seen in figure 1, it is interesting to see that focusing on biotech presents a very different picture. As figure 2 shows, the growth in internal co-authorships in the Øresund Region is similar to the increase in co-authorships with New Jersey/New York, while the remaining four regions have considerably lower growth rates. It is especially in the years following the opening of the Øresund Bridge in 2001 that the number of co-authorships has increased compared to the peers. Again, it is worth noticing that the collaboration with Stockholm has seen the least increase over the period. Growing consistently less than the internal partnerships in the Øresund Region, the gap has in particular widened since 2001.

Figure 3. Change in the average number of citations to biotech co-authorships, 1994-2008

Note: To reduce fluctuations, values are calculated based on 3-year averages of citations in the preceding, the actual and the following year. Values for 1994 and 2008 are 2-year averages. 2009 values are not available due to the 2-year citation lag.

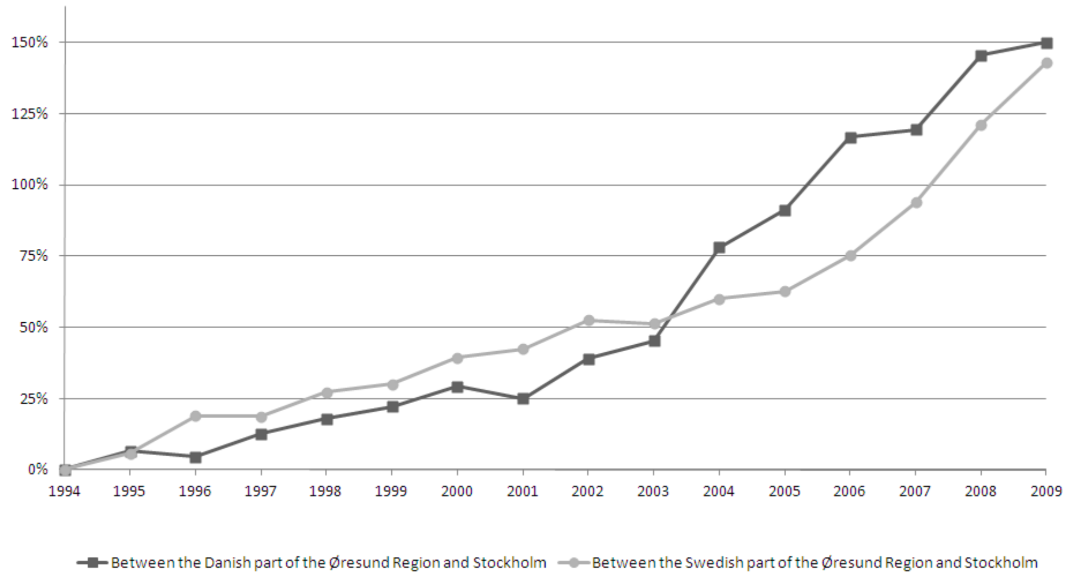
Source: Own calculations from ISI Web of Knowledge

Turning to the qualitative side of the co-authorships, figure 3 depicts the development in the average number of citations received by the biotech co-authorships within a two year window following publication. Again, the intra-regional collaborations in the Øresund Region do very well compared to the peer-group. The average number of citations triples in the period 1994-2001, followed by a slight decrease until 2006 where the growth returns. The co-authorships with Basel are the only among the peers which display similar growth rates, however, as the number of publications is much smaller, the development is also rather volatile. The development in citations to co-authorships between the Øresund Region and the other four regions remain relatively stable over time. The co-authorships with Île-de-France receive a decreasing number of citations over the years, while the collaborations with Stockholm improve towards the end of the period. The growth in co-authorships with Massachusetts and New Jersey/New York remains close to zero throughout the 15 years; however, the papers written with researchers from Massachusetts continue to receive the most citations among the six groups of co-authorships (see appendix table A2). Thus, while the quality of the biotech co-authorships between the Danish and Swedish parts of the Øresund Region has increased significantly, they are still not the most highly cited.

6.3. The Øresund Region and Stockholm

The graphs in the previous section demonstrate that the number of co-authorships with Stockholm has increased the least over the period, both overall and – particularly – within biotech. This section takes a closer look at the collaborations between the Øresund Region and Stockholm, distinguishing between co-authorships between the Danish and the Swedish parts of the Øresund Region. If the increasing integration in the Øresund Region affects the interactions with Stockholm, it can be expected that it will especially be researchers from Scania who will increasingly orientate themselves towards the Danish part of the Øresund Region rather than towards the Swedish capital.

Figure 4. Change in the total number of co-authorships in SCIE with Stockholm, 1994-2009

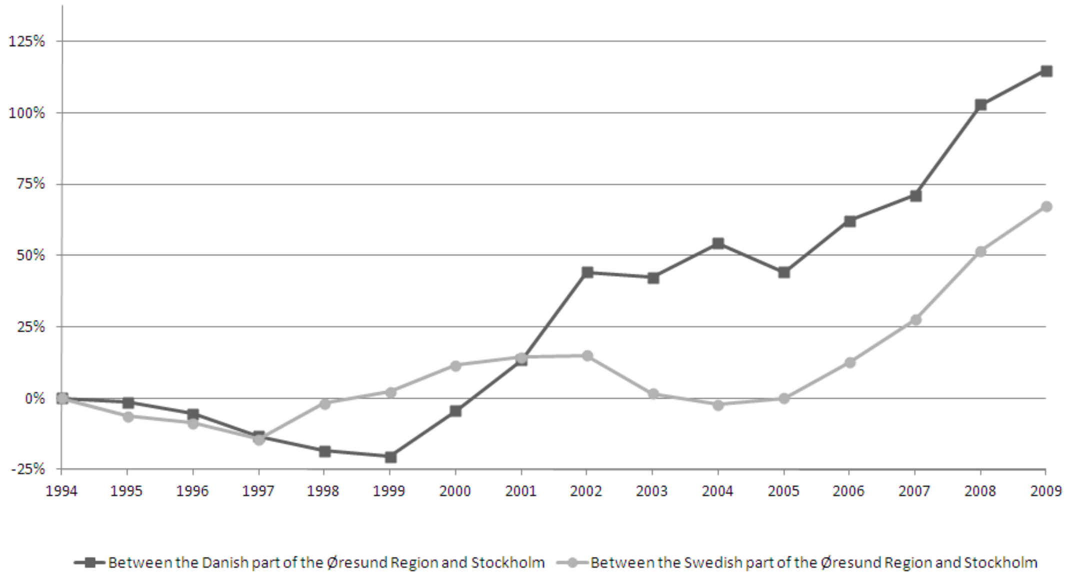


Note: To reduce fluctuations, values are calculated based on 3-year averages of the number of co-authorships in the preceding, the actual and the following year. Values for 1994 and 2009 are 2-year averages.

Source: Own calculations from ISI Web of Knowledge

In terms of all types of co-authorships included in SCIE, there appear to be only slight differences between the developments of the two parts of the Øresund Region (figure 4). The Scania-Stockholm collaboration has a higher growth in the first 10 years, but collaborations with the Danish part increase more towards the end of the period, and the overall growth over the 16 years is nearly similar. While the increasing importance of the Danish side compared to the Swedish after the opening of the Øresund Bridge may indicate a changing focus of the research environment in Scania, it is nevertheless not a very large effect. However, considering the relatively low growth in total co-authorships within the Øresund Region over the period (see figure 1) this is not highly surprising. Thus, it is in particular interesting to analyse the development within biotech where the integration between the two parts of the region appears to progress quickly.

Figure 5. Change in the number of biotech co-authorships with Stockholm, 1994-2009



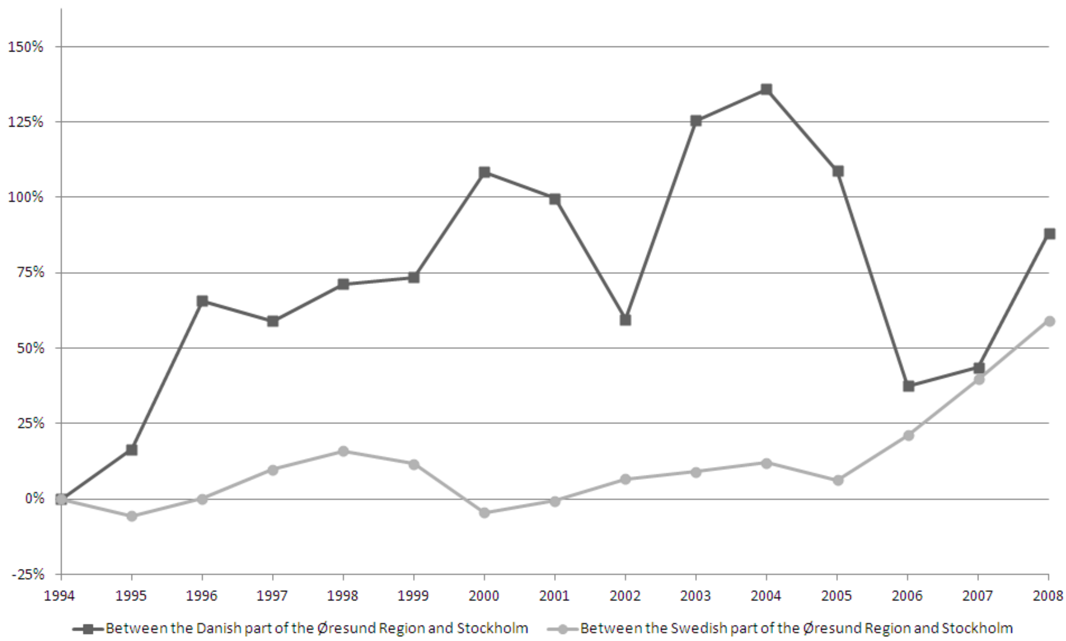
Note: To reduce fluctuations, values are calculated based on 3-year averages of the number of co-authorships in the preceding, the actual and the following year. Values for 1994 and 2009 are 2-year averages.

Source: Own calculations from ISI Web of Knowledge

As it can be seen from figure 5, the difference in the development between the Danish and Swedish collaboration with Stockholm is larger within biotech. After a decrease in the first part of the period, the number of co-authorships between the Danish part of the region and Stockholm starts growing significantly in the years around the opening of the fixed link between Denmark and Sweden. In these years, the number of Scania-Stockholm co-authorships is stable, or even decreasing slightly, before the collaboration activity starts increasing in 2005. Hence, this indicates that the regional integration in the Øresund Region does indeed impact the interaction with Stockholm; however, the effect appears to diminish with time.

Finally, figure 6 displays the development in the average number of citations to co-authorships with Stockholm. It is also seen that the growth in citations is significantly higher for the Danish part of the Øresund Region and Stockholm. Further, the development in citations to the Scania-Stockholm co-authorships is similar to the development in number of co-authorships: stable or slightly decreasing throughout most of the period, but increasing since 2005. Thus, in the years before and after the opening of the fixed link, researchers from Scania did not improve the quality of the collaborations with partners in Stockholm to the same extent as their Danish colleagues. This provides further support for the hypothesis that the increasing collaboration between researchers in the Øresund Region affects the collaboration with Stockholm, as researchers in Scania seem to give less priority to collaborations with Stockholm.

Figure 6. Change in the average number of citations to biotech co-authorships with Stockholm, 1994-2008



Note: To reduce fluctuations, values are calculated based on 3-year averages of citations in the preceding, the actual and the following year. Values for 1994 and 2008 are 2-year averages. 2009 values are not available due to the 2-year citation lag.

Source: Own calculations from ISI Web of Knowledge

7. Conclusion

While a growing body of literature is concerned with the topic of cross-border regions, few studies analyse these areas from an innovation system perspective. Thus, processes of integration and creation of multi-national knowledge spaces are so far poorly understood. This paper contributes to the understanding of these processes by analysing co-authorships between the Danish and Swedish parts of the Øresund Region over the period 1994 to 2009. Three main conclusions can be drawn from this case.

Firstly, the analysis indicates that investments in physical infrastructure do not by themselves lead to a higher level of integration and cross-border collaboration in the knowledge infrastructure part of the innovation system. The growth in co-authorships between the two parts of the Øresund Region is relatively low over the period, compared to the development in collaboration with other major research hubs, and there seems to be little effect of the opening of the fixed link between Denmark and Sweden.

However, secondly, the study also suggests that the removal of internal barriers in a cross-border region can have a substantial and long-term positive effect on knowledge flows if a targeted policy effort is made. Apart from being an important sector in both parts of the region, the Øresund biotech industry is also characterised by such a targeted policy effort through the Medicon Valley Alliance which was founded several years prior to the opening of the fixed link. Both the increase in the number of biotech co-authorships, as well as the amount of citations received by them, indicate that the combination of a competitive industry and designated cross-border policies makes it possible to exploit the possibilities offered by infrastructural investments through intensified interactions of increasing quality. Further, as this is the case for the biotech industry, which is characterised by an analytical knowledge base and a high dependency on global knowledge linkages (Coenen et al., 2004), it seems likely that similar effects can be achieved within industries with synthetic knowledge bases that rely on regional networks to a larger extent. It is therefore important to identify other sectors in the region where the Danish and Swedish firms and organisations complement each other and, hence, cross-border policies may stimulate collaboration.

Thirdly, the results of the study suggest that cross-border integration may indeed affect the linkages to other regions. The relatively low growth in co-authorships with Stockholm, especially within biotech and by organisations from the Swedish part of the Øresund Region, indicates that the growing integration of the Øresund biotech industry increasingly directs the attention of researchers from Scania towards the Danish part of the Øresund Region, rather than towards the Swedish capital. However, the analysis also indicates that this effect is particularly strong in the years around the opening of the fixed link and it diminishes substantially from 2005.

In order to move the study of cross-border innovation systems forward, the conclusions presented in this paper must be examined in other cross-border contexts. While the effect of integration on external knowledge linkages is in particular a question that needs to be considered in future research, the results of this analysis highlight important policy issues. At the most fundamental level, they point towards the relevance of cross-border policies as a crucial tool in the creation of integrated innovation systems. While it may cause some worry among national policymakers that successful cross-border integration can have a negative effect on intra-national knowledge flows, it must be remembered that this consequence is likely to be temporary. Rather, going back to the initial quote by Newman (2006), policymakers must focus on the possibilities arising from the creation of new knowledge linkages and efficient utilisation of resources across borders, so that they will not continue to be the lines that separate us.

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APPENDIX A

Table A1. Number of co-authorships

	1994-1997	1998-2001	2002-2005	2006-2009	Total
	All SCIE co-authorships				
Between the Danish and Swedish parts of the Øresund Region	**525**	**709**	**939**	**1,282**	**3,455**
Between Massachusetts and the Øresund Region	434	570	807	1,237	3,048
Between New Jersey/New York and the Øresund Region	**573**	**784**	**1,161**	**1,699**	**4,217**
Between Île-de-France and the Øresund Region	737	860	1,044	1,569	4,210
Between Basel and the Øresund Region	**81**	**107**	**216**	**245**	**649**
Between Stockholm and the Øresund Region	1,306	1,580	2,049	2,752	7,687
Between the Danish part of the Øresund Region and Stockholm	**514**	**625**	**807**	**1,144**	**3,090**
Between the Swedish part of the Øresund Region and Stockholm	928	1,128	1,335	1,757	5,148
	Biotech co-authorships				
Between the Danish and Swedish parts of the Øresund Region	**89**	**111**	**172**	**224**	**596**
Between Massachusetts and the Øresund Region	100	158	149	213	620
Between New Jersey/New York and the Øresund Region	**109**	**159**	**220**	**279**	**767**
Between Île-de-France and the Øresund Region	122	170	188	252	732
Between Basel and the Øresund Region	**32**	**44**	**43**	**52**	**171**
Between Stockholm and the Øresund Region	325	358	431	540	1,654
Between the Danish part of the Øresund Region and Stockholm	**126**	**124**	**200**	**250**	**700**
Between the Swedish part of the Øresund Region and Stockholm	210	249	244	323	1,026

Source: Own calculations from ISI Web of Knowledge

Table A2. Average number of citations to biotech co-authorships

	1994-1997	**1998-2001**	**2002-2005**	**2006-2008**
Between the Danish and Swedish parts of the Øresund Region	4.5	6.8	7.2	11.0
Between Massachusetts and the Øresund Region	14.6	11.1	12.9	20.8
Between New Jersey/New York and the Øresund Region	11.2	12.5	12.6	13.1
Between Île-de-France and the Øresund Region	12.1	9.8	8.7	12.7
Between Basel and the Øresund Region	4.4	13.8	14.8	10.3
Between Stockholm and the Øresund Region	6.4	7.1	8.5	8.0
Between the Danish part of the Øresund Region and Stockholm	8.1	9.9	11.7	8.6
Between the Swedish part of the Øresund Region and Stockholm	5.4	5.7	6.2	7.9

Source: Own calculations from ISI Web of Knowledge

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PAPER IV

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This co-authorship declaration applies to the following paper:

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The two authors contributed to the paper in the following ways:

Teis Hansen has essentially:
- Formulated the focus, problem and conceptual basis of the paper
- Prepared and performed the field work
- Carried out the analysis
- Presented and drafted the paper

Lars Winther has:
- Contributed to formulating the focus, problem and conceptual basis of the paper
- Contributed to writing the theoretical framework of the paper

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Article

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Innovation, regional development and relations between high- and low-tech industries

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Abstract

The current European policy agenda strongly accentuates the importance of research and development (R&D) as a driver of economic growth. The basic assumption is that high European wage levels make it unlikely that less research-intensive parts of the economy can withstand competition from low-wage countries with increasingly skilled labour forces. Thus, the inferior growth of the European Union (EU) in the 1990s compared with the USA has been explained by the latter's higher rate of R&D investments. The paper challenges this rather simplistic view of innovation and examines the regional consequences of such policies. EU growth has caught up with that of the USA during recent years and low-tech industries continue to have considerable economic importance in Europe in terms of jobs and value added, especially outside the main growth regions, but also in the major urban regions. Empirical evidence from Denmark and the UK provided in the paper suggests that low- and high-tech industries are closely interconnected because low-tech firms play important roles both as partners in the innovation processes of high-tech firms and as buyers of high-tech products. Therefore, EU industrial policy is not appropriate because it overlooks the continuing significance of low-tech industries. Furthermore, the rather uniform focus on R&D is associated with a strong emphasis on large city-regions where research-intensive industries are concentrated and, thus, increasing regional inequality in Europe is being produced.

Keywords

EU industrial policy, firm linkages, innovation, low-tech industries, regional inequality

Introduction

This paper examines the importance of innovation in low-tech industries as a driver of economic growth and contrasts this with the strong emphasis on 'science-push' in European policymaking. It is argued that the failure to recognize the interdependency of high- and low-tech industries will restrain economic development, including perspectives for less favoured regions. Furthermore, a continuing focus by European governments and the European Union (EU) on the importance of research and

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development (R&D) for economic growth will increase interregional inequality owing to the inability of peripheral regions to compete for especially high-tech industries, which tend to favour city-regions. Thus, there is a strong bias towards city-regions, where research-intensive firms are concentrated, in current industrial policymaking.

The relatively low amount of R&D investment in Europe relative to the USA has frequently been emphasized as a main explanation for the latter's higher GDP growth and productivity during the 1990s (e.g. Sapir et al., 2003; European Commission, 2004). The underlying assumption is that the high European wage levels make it unlikely that the less research-intensive parts of the economy can withstand competition from low-wage countries with increasingly skilled labour forces. Consequently, continuous investments in R&D leading to radical innovations are prioritized to achieve long-term economic prosperity. Associated with this is a focus on high-tech industries defined by their R&D intensity and subsequently on the regions, often large city-regions, where these industries are concentrated. Thus, industries with lower R&D intensity are receiving decreasing attention by policy makers and this will in the end also have significant effects on regions focused mainly on low-tech industries.

The aim of this paper is to challenge this close relationship between, on the one hand, R&D and high-tech industries and, on the other hand, (regional) economic growth. Previous work has contested the background for the so-called productivity gap between the USA and the EU and concludes that explanations for differences in growth are based on a number of factors (Dunford, 2005a, 2005b). Additionally, growth rates in Europe have been higher than in the USA in recent years, which further erodes the argument focusing solely on the differences in R&D investments. Also it is hard to find evidence for the expected superior performance of European high-tech industries during the last few decades compared with industries with lower R&D intensity. This conclusion will be documented below.

The reasons for the continuing competitiveness of European low-tech industries have recently attracted attention from some scholars (Bender and Laestadius, 2005; Hirsch-Kreinsen et al., 2006; Radauer and Streicher, 2007; Kirner et al., 2009; Hansen, 2010). Prominence in these studies is given to innovation strategies focusing on step-by-step developments of products, refinement and specialization of production processes, and customization of products (Hirsch-Kreinsen, 2008). The significance of these innovation processes has been analysed elsewhere and the empirical focus of this paper is instead on the interconnectedness between low- and high-tech industries. It is often forgotten that low-tech firms fulfil important roles both as partners in high-tech firms' innovation processes and as buyers of high-tech products. These aspects are described on the basis of 31 interviews with key actors from UK and Danish low-tech firms and industrial organizations.

The main argument presented on the basis of this analysis is that the development paths of high- and low-tech industries are highly interconnected and the importance of R&D for European economic development should not be overstated. It is a very simplistic view to consider increasing R&D funding as the key to future economic prosperity in Europe, when industrial development depends on multiple relations within and across industries in various stages of the production process. Yet, there is a tendency among policy makers to exaggerate the crucial character of R&D and high-tech industries, thereby overlooking the continuing weight of low-tech industries as well as the interdependence of low- and high-tech industries. There are no reasons to regard policies stimulating incremental innovation and adaptation of technologies in low-tech industries and policies facilitating cooperation between high- and low-tech firms as less important for economic growth than policies aiming at stimulating spending on R&D.

Regions, knowledge and innovation

A strong consequence of globalization in the form of, for instance, trade liberalization and improved infrastructure is pressure on the competitiveness of firms in the industrialized countries. Further, the increasing global diffusion of knowledge leads to higher productivity in low-wage countries, and a continuous creation of knowledge is therefore necessary if the industrialized countries are to maintain their competitive advantage (Maskell and Malmberg, 1999). Thus, recently there has been a significant focus on the knowledge economy and high-tech industries and especially on radical innovations and the analytical knowledge base in studies of regional development, national innovation systems and the EU's competitiveness. The knowledge economy has emphasized the importance of innovation in generating competitive firms, nation-states, cities and regions. The spatial consequence of this focus is a marked concentration of interest on the resurgence of the large city-regions (Scott, 2008; Hansen and Winther, 2010), learning regions (Morgan, 1997) and high-tech regions (Asheim and Coenen, 2006). The competitiveness of firms and hence cities and regions, it is argued, increasingly depends on their ability to innovate by improving their productivity through process innovation, including new forms of organization, product quality or producing new products (David and Foray, 2002), which is very similar to the definition formulated by Schumpeter (1943). However, innovation is more complex than just a focus on R&D-based innovations and high-tech learning. According to Amin and Cohendet (2004), a critical aspect of the innovation process is knowledge and the understanding of knowledge production as an interactive, relational learning process because knowledge contains an innovative potential, but knowledge does not become innovation before it is introduced on the market (Edquist, 1997). Whether this happens depends on the cost related to implementing this knowledge and the likely gains on the market (Rigby, 2003).

Thus, one way to distinguish between innovations is to consider their relation to current technology. A constant improvement of a product or a production process is considered as an *incremental innovation*, because it is not fundamentally different from well-known technologies. A *radical innovation*, in contrast to incremental change, is completely different from the current products or processes available on the market, and a number of related radical innovations can together constitute a technological revolution, which has great impact on society as a whole (Fagerberg, 2005).

Whether firms in an industry primarily create incremental or radical innovations depends fundamentally on the characteristics of the industry, including the skills of the workforce – this can overall be termed the industrial knowledge base (Asheim and Gertler, 2005; Asheim and Coenen, 2006) and is related to the frameworks of national and regional innovation systems (Lundvall, 1992; Cooke, 2001), hence including the institutional framework of the innovation process. Asheim and Gertler (2005) distinguish between two main industrial knowledge bases. An *analytical knowledge base* is characterized by an emphasis on knowledge creation through the use of scientific methods and modelling. The links between research institutions, universities and firms are consequently of great importance for this kind of knowledge production. The use of codified knowledge is extensive, and the results are most often also codified and documented through patents and publications – but even highly codified knowledge requires tacit knowledge to implement (Nonaka and Takeuchi, 1995; Amin and Cohendet, 2004). Overall, these characteristics imply that most innovations based on an analytical knowledge base are radical.

The *synthetic knowledge base* utilizes existing knowledge rather than creating completely new knowledge and hence is in contrast to the analytical knowledge base. The availability of workers with practical and engineering skills is regarded as essential, and tacit knowledge, learning-by-doing and learning-by-using therefore have a greater importance than the scientific-based codified knowledge. The objective of the innovation process is often to solve specific problems for a customer, and the relations between agents/firms in the commodity chain are thus of significant importance for producing new innovations. A knowledge base with these attributes will therefore primarily produce incremental innovations.

Obviously, many firms combine the two ideal types of knowledge base. In fact, Jensen et al. (2007) find that such firms tend to be more innovative than firms relying on only one of the two knowledge bases. Jensen et al. (2007) confirm how the Science, Technology and Innovation (STI) mode (associated with the analytical knowledge base) and the Doing, Using and Interacting (DUI) mode (associated with the synthetic knowledge base) complement each other: experiences and practical knowledge are frequently essential for scientists working in R&D departments of high-tech firms in the process of designing research projects and interpreting results. Similarly, scientific knowledge is often part of the solution for firms that otherwise emphasize learning-by-doing and learning-by-using. Accordingly, the STI and DUI modes are not entirely dependent on the analytical and synthetic knowledge base, respectively, but include elements from both (Asheim, 2009).

The radical innovations that derive from an analytical knowledge base are given prominence over incremental innovations in the work of Schumpeter (Fagerberg, 2005). Schumpeter (1943: 117) notes that '[t]echnological progress is increasingly becoming the business of teams of trained specialists', and Vannevar Bush describes innovation as a set of strict calculations, where scientific research constitutes the first stage in the development of an innovation, followed by product development, production and finally marketing (Bush, 1945). However, several important criticisms of this model, which has subsequently been termed the linear model of innovation, have been raised (Nelson and Winter, 1982; Dosi et al., 1988; Lundvall, 1992; Nonaka et al., 1996; Edquist, 1997; Amin and Cohendet, 2004). Firstly, few innovations actually happen in this way. Innovations are often driven by demand or result from new ways of combining known knowledge. The importance of science-based knowledge production is hence exaggerated and the learning processes are highly complex, crossing various communities (Amin and Cohendet, 2004). Secondly, the interactions and feedbacks from customers and suppliers are important in innovation processes, but the linear model ignores this (Henry et al., 1995). This, of course, led to the development of *the chain-linked model of innovation* (Kline and Rosenberg, 1986), which describes innovation processes as complex and disorderly. In line with this, we will show in the empirical part of this paper that a key flaw of the linear model of innovation is the failure to consider the interrelations between high- and low-tech firms for innovation processes.

Measuring innovation

The linear model of innovation was very influential in the decades following the Second World War (Cooke and Morgan, 1998). The term itself was not introduced before the late 1960s (Edgerton, 2004), but the idea of a linear innovation process developed through the 20th century. Statistics offices played a key role in the crystallization of the model into a social fact and the collection of data on basic research, applied research, and development continues to be an important reason for the persistent significance of the model in the eyes of policy makers (Godin, 2006), including those in the EU too, as we shall see below.

An important way in which the science-based view of innovation influences policymaking is through industrial classifications based on this model of innovation. The most influential classification system is the one used by the OECD and Eurostat, which is based on the R&D intensity of different industries. Outcomes of R&D are characterized by significant elements of novelty and scientific or technological progress (OECD, 2002), and the R&D intensity depends on the ratio of R&D expenditures to the output value of the sector. Four categories are used (Smith, 2005):

1. High-tech industries: R&D intensity above 5 percent.
2. Medium–high-tech industries: R&D intensity between 3 percent and 5 percent.
3. Medium–low-tech industries: R&D intensity between 1 percent and 3 percent.
4. Low-tech industries: R&D intensity below 1 percent.

Table 1 shows the resulting classification by the Organisation for Economic Co-operation and Development (OECD) of manufacturing industries. A newer version following the NACE rev. 2 has been introduced (Eurostat, 2009), but the latest available data on industries' value added are from 2006 and thus follow NACE rev. 1.1.

Lately, organizations such as the OECD have started to put more emphasis on issues such as capital input from knowledge-intensive industries and

Table 1. Manufacturing industries classified according to R&D intensity (NACE rev. 1.1 codes in brackets)

High-tech	Medium–high-tech
Pharmaceuticals (24.4)	Chemicals – excl. pharmaceuticals (24 excl. 24.4)
Computers, office machinery (30)	Non-electrical machinery (29)
Electronics–communications (32)	Electrical machinery (31)
Scientific instruments (33)	Motor vehicles (34)
Aerospace (35.3)	Other transport equipment (35.2+35.4+35.5)
Medium–low-tech	Low-tech
Coke, refined petroleum products and nuclear fuel (23)	Wood, pulp, paper products, printing and publishing (20–22)
Rubber and plastic products (25)	Food, beverages and tobacco (15–16)
Non-metallic mineral products (26)	Textile and clothing (17–19)
Basic metals (27)	Other manufacturing and recycling (36–37)
Fabricated metal products (28)	
Shipbuilding (35.1)	

Source: OECD (2004).

human capital (OECD, 2007) and to highlight intangible investments rather than merely R&D investments (OECD, 2009). However, the overall focus on R&D intensity persists among public policy makers. The simplicity of this taxonomy makes it very attractive in a policy context, because it is very precise and easy to measure (Jacobson and Heanue, 2005; Godin, 2006), in contrast to the more detailed alternatives that have been developed over the years. Pavitt (1984) presents a taxonomy that overcomes this limited view of innovation: it includes innovation through the employment of skilled employees, learning-by-doing and learning-by-using. Firms can therefore be considered as high-tech even though the actual R&D intensity is relatively low. Another alternative is developed by Bar-El and Felsenstein (1989) where the technological intensity of an industry depends on the percentage of academic and skilled labour, the technological intensity of capital (investments in sophisticated machinery or processes), and the technological intensity of the product (R&D intensity). Finally, Laestadius et al. (2005) present an attempt to combine the work of previous scholars. As well as arguing for the inclusion of similar measures to those of Pavitt (1984) and Bar-El and Felsenstein (1989), they stress the importance of a number of other indicators. Measures reflecting the ability to design solutions through synthesizing different fields of knowledge and indicators measuring organizing capacity are seen as necessary to describe the full innovativeness of firms and sectors. Further, they state that describing the innovativeness of industries through one innovation indicator is reductionism. A complex issue such as innovation needs different indicators, which cannot be compiled into one.

European innovation policy

These alternative and more detailed taxonomies have, however, had limited impact, and, among policy makers, innovation continues to be closely related to the taxonomy based on R&D intensity (Jacobson and Heanue, 2005). Sectors with lower R&D intensity are regarded as being less important for long-term economic growth and manufacturing in particular is given a low priority, both by the EU (Hirsch-Kreinsen, 2005) and by national governments, for example in the UK (Turok, 2004) and Denmark (Hansen, 2010). Increasing investment in R&D has been a key policy priority since the Lisbon Strategy established the EU target for R&D spending at 3 percent of GDP. The influential Sapir Report found that EU economic growth has been inferior compared with the USA and that low levels of investment in R&D are an important reason for this. A central recommendation of the report was that the EU should focus on reducing international economic differences and leave the responsibility for intra-national inequality to the individual member states. Associated with this alteration of the previous coherence of policy was an emphasis on growing regions and investment in R&D (Sapir et al., 2003), which does not take the diversity of European regions into account (Birch et al., 2010).

A number of other EU reports have dealt with the connection between growth and R&D investment. The annual European Competitiveness Reports highlight the importance of high-tech industries and R&D investment for future economic growth, but their view on competitiveness is quite broad compared with that found in other reports published by the European Commission, where it is evident that a knowledge-based economy is considered to be very closely linked to the significance of R&D. Examples include the innovation scoreboards (Hollanders et al., 2009), the so-called Aho Report prepared after the revision of the Lisbon Strategy (European Commission, 2006b), and the process of producing indicators for monitoring the development of the European Research Area (European Commission, 2008).[1] In some instances, it appears as if increasing R&D investment is a goal in itself rather than a means to achieve stronger economic growth:

> Given the weight of high-tech sectors in the overall level of business R&D intensity, a change should include the sectoral composition of the business sector, a move towards a higher share of high-tech companies and research-driven clusters. (European Commission, 2008: 11)

Thus, it is stated that it is a policy challenge to 'change the balance of the industrial structure in favour of these research-intensive sectors' (European Commission, 2008: 16), implying that development of low-tech industries is to be given a low priority. An important argument for this emphasis on high-tech industries and R&D policies has been the superior economic performance of the USA, which has traditionally invested a higher percentage of GDP in R&D (European Commission, 2004). The illuminating work of Boltho (2003), Gordon (2004) and Dunford (2005a, 2005b) has, however, questioned the background for the apparently inferior economic performance of the EU compared with that of the USA.

Firstly, productivity growth in the EU outperformed that in the USA between 1989 and 2002, although GDP grew more slowly as the average number of working hours decreased in Europe. This development is largely voluntary – it is a trade-off in favour of leisure time that maximizes the welfare of people – and a lower GDP growth should therefore not necessarily be a concern.

Secondly, a number of factors increase GDP in the USA without improving welfare, such as demand for heating and air-conditioning because of climate conditions, the need for car journeys owing to a lack of public transport, security measures as a result of high crime rates and litigation resulting from a relatively low degree of interpersonal trust in US society.

Finally, a number factors have contributed to increase and decrease growth in the USA and the EU, respectively, including the escalating indebtedness of US households and the US economy, restrictive EU macroeconomic measures such as the monetary policy of the European Central Bank and the EU's stability and growth pact, as well as the large costs in the 1990s associated with the German reunification.

Thus, there are many issues that need to be taken into consideration when the economic development of the EU and the USA is compared. Moreover, EU GDP per capita growth rates have caught up with the USA in recent years. The USA achieved the largest GDP per capita growth rates through most of the 1990s, but the picture changed after the millennium and the burst of the IT bubble. Figure 1 reveals that, looking at the period as a whole, growth in the EU and the USA has been almost the same. Taking 1989 as a baseline (index = 100), EU per capita GDP growth reached an index value of 137.4 in 2008, slightly surpassed by the USA with a figure of 137.5. Thus, taken as a whole, there seems to be little relevance in arguing for a greater emphasis on R&D in European policymaking on the basis of the performance of the US economy. The next section will examine whether the underlying assumption that technology-intensive industries have superior

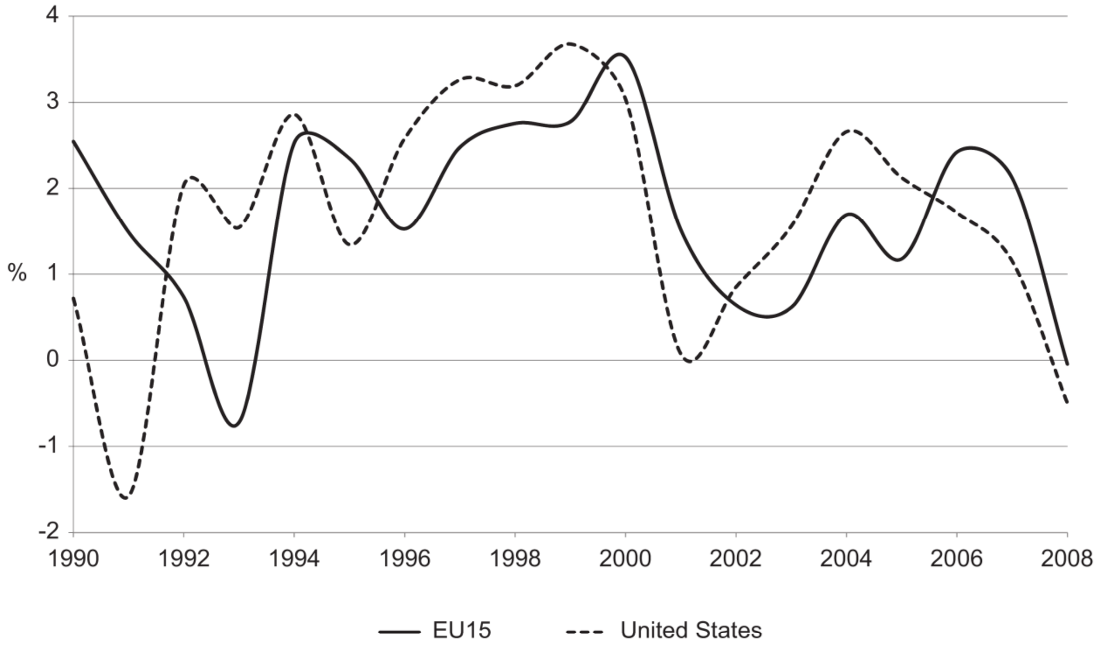

Figure 1. GDP per capita, year-on-year growth rates: EU15 and USA, 1990–2008 (constant prices and PPP)
Source: Own elaboration on the basis of figures from OECD's STAN database.

competitiveness compared with low- and medium–low-tech industries can be supported empirically.

The economic importance of low- and medium–low-tech industries in Europe

The importance of low- and medium–low-tech (LMT) industries for the industrialized economies is widespread. Kaloudis et al. (2005) show that low-tech industries remained of key importance in a sample of 11 OECD countries in terms of both employment and value added over the period 1980–99. A similar conclusion can be reached by studying industrial development in 12 European OECD countries – Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Portugal, Spain, Sweden and the UK – from 1995 to 2006.

Figure 2 shows the development in share of gross value added according to R&D intensity. The low-tech sector's share fell by a little less than 4 percentage points from 1995 to 2006, while the two medium-tech sectors experienced minor increases of approximately 1 percentage point. Interestingly, the share of the high-tech sector has been very stable over the years: the share initially increased from 10.2 percent in 1995 to 12.3 percent in 2000, but since then has varied only between 11.8 percent and 12.3 percent. Furthermore, the total value added of the high-tech sector is significantly lower than the value added of the three other sectors.

The overall picture is thus one of stability: the LMT industries continue to play a key role in the economic development of European countries even though their share of value added has decreased over the period. The same can be said in terms of the different sectors' shares of manufacturing employment (Figure 3). Employment in the low-tech sector in 10 European countries – the Netherlands and the United Kingdom are excluded owing to data availability – continues to account for by far the largest share, though it did decrease by approximately 3 percentage points between 1995 and 2006. Conversely, the shares of the medium–low-tech and the medium–high-tech sectors increased by, respectively, 1.7

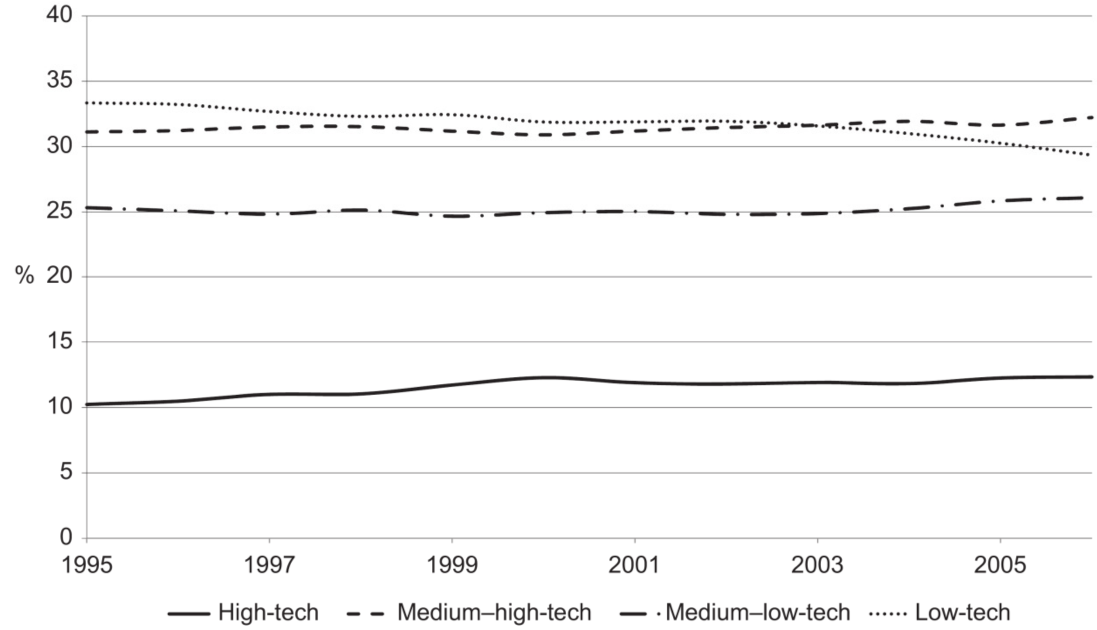

Figure 2. Shares of manufacturing value added for 12 European countries, 1995–2006 (percent)
Source: Own elaboration on the basis of figures from OECD's STAN database.

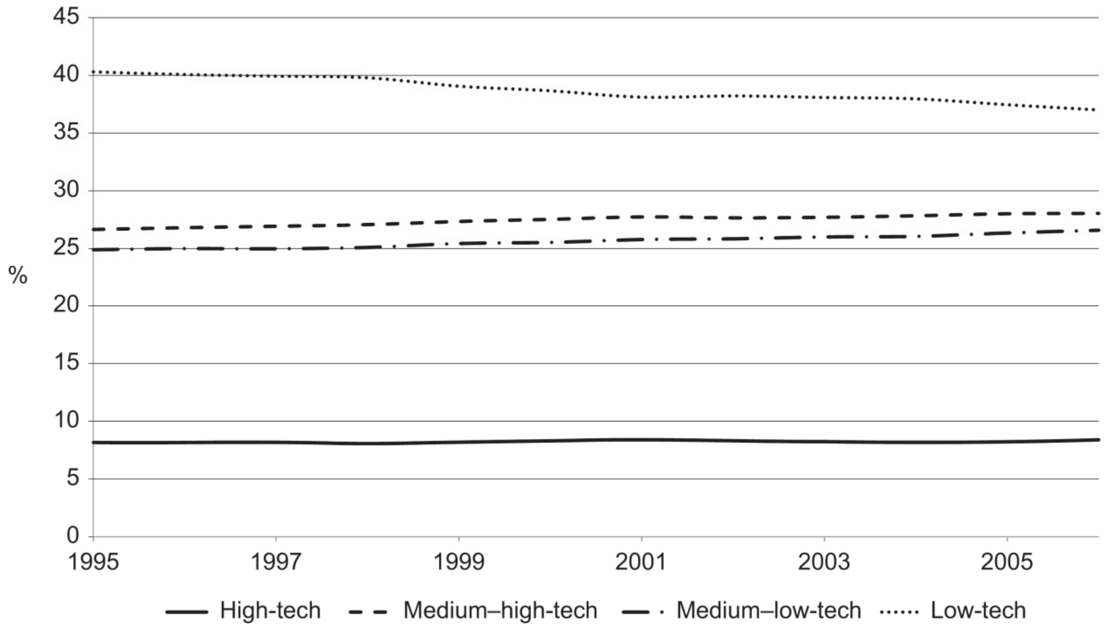

Figure 3. Shares of manufacturing employment for 10 European countries, 1995–2006 (percent)
Source: Own elaboration on the basis of figures from OECD's STAN database.

percent and 1.4 percent. It is notable that the high-tech sector's share of employment remained completely stable over the period, fluctuating only between 8.1 percent and 8.4 percent.

A further interesting analysis is to compare the development of labour productivity (value added per employee) for the four different sectors. Unfortunately, detailed statistics on the number of

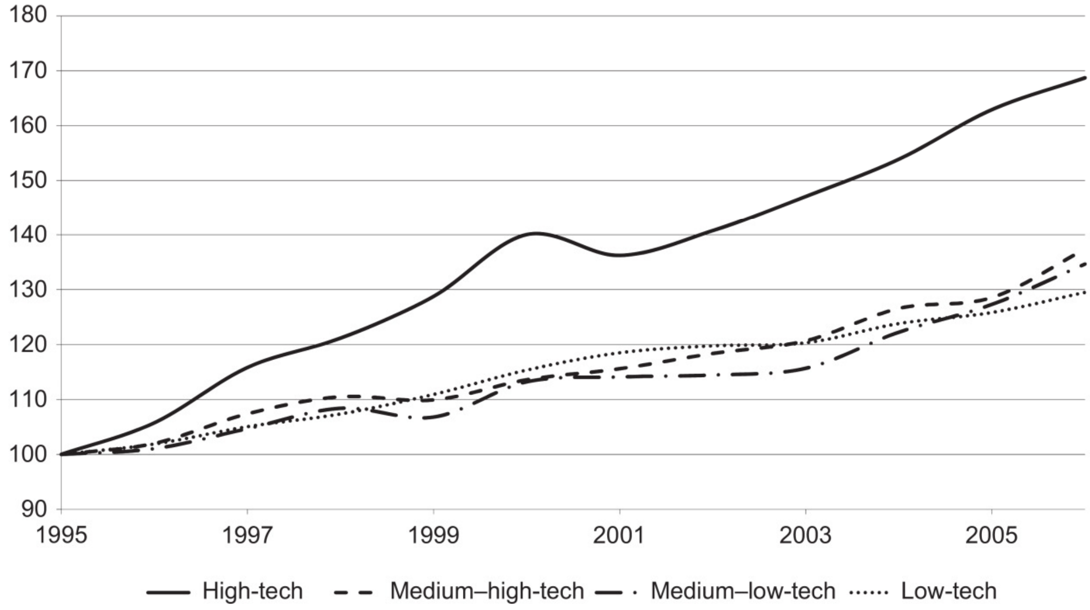

Figure 4. Value added per employee for 10 European countries, 1995–2006 (1995 = index 100)
Source: Own elaboration on the basis of figures from OECD's STAN database.

hours worked according to the industries' R&D intensity are not available, and the size of employment is therefore used as an input variable even though there might be inter-sectoral differences. This is, however, not considered a major problem, because development over time is our main interest.

All four sectors have seen increasing levels of labour productivity but, taking 1995 as the point of reference, it is seen from Figure 4 that the index value of the high-tech sector increased the most. It is furthermore interesting to see that the development of the three other sectors was very similar over the period. However, including only the years since the millennium provides a different picture (see Figure 5 – the scale of the *y*-axis is similar to that of Figure 4 to aid comparison): since 2000, few differences can be observed between the four sectors, even though the growth of labour productivity in the low-tech sector was somewhat below that in the other three sectors in 2005 and 2006. The most important observation is nevertheless that the high-tech sector's superior growth rates in labour productivity from the second part of the 1990s did not continue – the high-tech growth rate is now comparable to that of the other sectors.

Overall, the data show that even though the growth rates of R&D-intensive industries were high from 1995 to 2006 in terms of value added and labour productivity, no radical change has taken place in the composition of the European manufacturing sector: the total value added of LMT industries is significant and it continues to increase. Furthermore, these industries maintain a crucial role in terms of employment, as they account for more than 63 percent of all manufacturing jobs. Finally, the growth of LMT labour productivity did not develop significantly differently from that of high-tech industries in the period after the millennium. In general, there seems to be little empirical evidence for maintaining an excessive policy focus on high-tech industries and thereby neglecting LMT industries.

The value added of LMT industries

The puzzle of how LMT firms remain competitive in high-wage countries has in recent years been studied on a number of occasions, including a cross-European study (Bender and Laestadius, 2005;

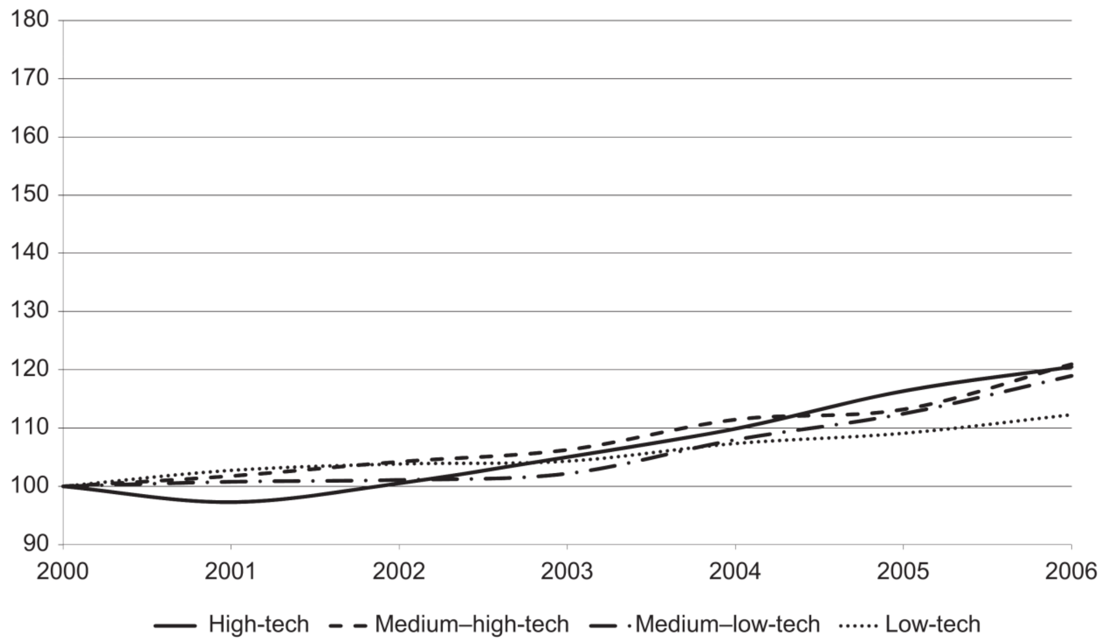

Figure 5. Value added per employee for 10 European countries, 2000–6 (2000 = index 100)
Source: Own elaboration on the basis of figures from OECD's STAN database.

Hirsch-Kreinsen et al., 2006), case studies in Austria (Radauer and Streicher, 2007), Taiwan (Chen, 2009) and Denmark (Hansen, 2010), and analyses of LMT sectors in Germany (Kirner et al., 2009) and Spain (Santamaria et al., 2009). The studies show how LMT firms utilize their mainly synthetic knowledge base in a number of ways. The most widespread innovation strategies are described by Hirsch-Kreinsen (2008) as follows:

- *Step-by-step* is based on a continuous improvement of the product produced.
- *Customer orientation* combines existing knowledge in new ways in order to develop tailored products and solutions.
- *Process specialization* focuses on improving the technical organizational process structures.

In addition to the value added created directly in LMT industries, it is often forgotten that low-tech firms fulfil important roles both as partners in the innovation processes of high-tech firms' and as buyers of high-tech products (a notable exception being Robertson and Patel, 2005).[2] Thus, the interconnectedness of low- and high-tech industries is also of significant importance for economic development in high-tech industries.

The following section explores these issues drawing on 31 interviews with key actors from UK and Danish firms (25 interviews) and with industrial organizations (6 interviews) from the fabricated metal and plastics industries. The two industries were chosen because they are among the most important non-research-intensive industries in Europe, in terms of both employment and value added. Interviews took place in two countries in order to reduce the risk of capturing nation-specific trends, but no striking differences have been found between the Danish and UK firms. Firms of different sizes were interviewed, but we do not claim any representativeness – the aim of the analysis is to gain an insight into innovation dynamics and the interactions between high- and low-tech firms, not to generalize about innovation characteristics in the fabricated metal and plastics industries. Still, key characteristics of the firms and comparison with

Table 2. Characteristics of interviewed firms compared with the populations (percent)

	Interviewed firms	Population (case area)	Population (Country)
Danish fabricated metal and plastics firms			
Employment size distribution (2009)			
5–49 employees	69	79	85
50–249 employees	23	17	13
+ 249 employees	8	4	3
Share of firms exporting (2009)			
Exporting firms	69	47	n/a
Main product focus (2009)			
For end users	31	28	n/a
For further processing	69	73	n/a
UK fabricated metal and plastics firms			
Employment size distribution (2010)			
5–49 employees	50	88	89
50–249 employees	33	10	10
+ 249 employees	17	2	1
Turnover size distribution (2010)			
£50,000–£249,000	17	42	46
£250,000–£999,000	33	31	30
£1,000,000+	50	27	24

Note: UK case area = West Midlands and Yorkshire and the Humber; thus the figures also include firms located in the urban areas that were not considered for the interviews.
Sources: Own data collection, figures from KOB's database and ONS (2010).

the overall populations are given in Table 2. Unfortunately, not all information is available for both Danish and UK firms, but the interviewed firms are generally larger than the wider populations of the fabricated metal and plastics firms in the two countries in terms of employment and turnover (UK figures only). Further, the interviewed Danish firms are more likely to export goods as well as to serve end users rather than producing intermediate outputs.

The Danish firms are located in the region around the fourth-largest city in Denmark, Aalborg, while the UK firms are from the West Midlands and Yorkshire, in the area between Birmingham and Leeds. The firms are thus comparable, because they are located neither in large cities nor in the most peripheral parts of the two countries. We selected these particular regions because we are primarily interested in the interactions of firms located in such areas and, furthermore, we want to ensure that the industries are of considerable economic importance in the regions. The two areas fulfil both of these conditions.

Purchasers of radical innovations

Analyses of inter-industry technology flows were pioneered by Scherer (1982), who showed how LMT industries are important purchasers of technologies from industries with high R&D intensity. Sector studies in the construction industry (Arditi et al., 1997) and the plastics industry (Patrucco, 2005) have since confirmed the dense linkages with more research-intensive industries. The technological interdependence among industries has increased over time as sourcing of technology becomes of greater importance (Robson et al., 1988). Use of advanced machinery has recently been identified as a central source of innovation for

LMT firms (Heidenreich, 2009; Santamaria et al., 2009), and purchasing capital goods with inbuilt R&D is also of considerable importance to the innovation strategies of most of the firms interviewed in this study. One vice president of a Danish fabricated metal firm explained how recently acquired computed numerically controlled (CNC) machines can be programmed to work through the night without monitoring, resulting in significant productivity improvements. A second example is given by a department manager who described how new industrial robots and close cooperation with suppliers have minimized the firm's expenses associated with welding.

Thus, the suppliers of these technologies are essential for the diffusion of scientific and engineering knowledge to LMT firms, which they can apply in their own innovation processes (Storper, 1997). At the same time, the rate of return to technological innovations is positively correlated with their diffusion. Interestingly, there is a general awareness among the LMT firms that they are in a strong negotiating position vis-à-vis the suppliers of machinery and technological equipment. As one interviewee phrased it:

> 'Yes, access to their technology is important for us. But access to our funds is just as important for them.' (Head of Production, Danish fabricated metal firm)

An industry representative expressed a similar viewpoint:

> 'Our firms are tired of being labelled as non-innovative because they have a limited R&D budget. The amount of funds used on capital expenditure is equally important to get a full picture of innovativeness.' (Operations Director, UK industrial organization)

Accordingly, the emerging picture is one of interdependency where firms indirectly benefit from R&D but also indirectly pay for it. LMT firms account for 64 percent of total industry expenditure in Denmark (Statistics Denmark, 2009) and it is apparent from the interviews that they are aware of the significant economic influence that they exert.

Joint developments of radical innovations

Both Robertson and Patel (2005) and Mendonca (2009) find that LMT firms are increasingly diversifying into high-tech fields and patent products within these areas. However, both contributions focus on the patenting activity of very large LMT firms and it is questionable whether a similar pattern is evident among small and medium enterprises – at least the importance of patents is limited among the firms interviewed for this study. Yet, the frequency of joint innovation projects between high- and low-tech firms is high among the firms interviewed. Following Jensen et al. (2007), it shows how it is often necessary to combine the STI and DUI modes of innovation, in these instances by creating inter-firm collaborations. Thus, the following three cases exemplify how LMT firms today often are heavily involved in high-tech firms' innovation processes.

The first example is a UK manufacturer of plastic products that has increasingly been targeting the pharmaceutical industry, in terms of both the construction of clean rooms and the production of drug delivery devices. The firm identified a lack of plastics-specific knowledge among many pharmaceutical firms and has during the past decade become heavily involved in collaborative innovation projects in areas from medical devices to production facilities, most notably clean rooms. The firm's Business Development Manager emphasized that the collaborations led to results that would be beyond the reach of the firms individually: production time had for instance been reduced by one half on some products by combining the R&D efforts of pharmaceutical firms with the plastic producer's knowledge of materials. Naturally, a halved production time is crucial for firms in the pharmaceutical industry, where a fast or a slow market entry can make the difference between a commercial success and a failure. Furthermore, this collaboration was of great value to the plastics manufacturer, who received access to unique knowledge and references:

> 'The knowledge we gained in this partnership is now providing us with a competitive advantage. We have

> just negotiated a similar project where time is also an important factor. It was very beneficial for us to be able to prove that we have managed such a project before.' (Business Development Manager, UK plastics firm)

This case exemplifies the potential mutual benefits to high- and low-tech firms of such collaborations –in terms of execution time, knowledge build-up and market access.

Further examples derive from several major UK manufacturers of metal products that have joined forces by acquiring a software development firm. The subsidiary specializes in software used for the design and production of steel beams, which is given away free in order to sell the products of the four parent firms. According to the General Manager, innovations are here again a product of R&D carried out in the software development firm combined with the knowledge of materials and production techniques in the fabricated metal firms. As the following quote demonstrates, it was initially necessary to devote time and resources to the collaboration; however it was a good long-term investment:

> 'At first we had to learn to speak the same language, but this ability is now one of our key assets.' (General Manager, UK fabricated metal firm)

The interactions between the parents and the subsidiary illustrate well the functioning of the chain-linked model of innovation: the parents initiate development projects when they detect new market needs, for example the ability of the software to optimize the trade-off between weight, insulation and fire protection. Naturally, the software development itself is carried out by the subsidiary, but employees from the parent companies are constantly involved in the project to ensure that the characteristics of the steel are adequately simulated in the software. Following this, the parent companies take the software through a testing phase, before the final adjustments are made by the subsidiary, and it is ready for distribution among the customers. This illustrates how intense communication between people with very different competencies is taking place at various stages of the production process.

The final example is a Danish firm producing stainless steel products. This firm has signed development contracts with its closest technological suppliers, which give exclusive rights or at least advantageous sourcing conditions to the products developed under these agreements. Consequently, the firm's Project Manager describes the suppliers as 'an ad hoc pool of development staff'. In this case, the LMT firms act as a demanding customer (following von Hippel, 1988) who directly funds research in high-tech industries. Yet again, this underlines how LMT firms also stimulate economic development in research-intensive industries as well as the complexity of innovation processes: here, the starting point is the production processes of the LMT firm, not research in high-tech firms.

In addition to the value of common innovation projects, the interviews also pointed to the importance of the LMT firms' role as 'translators' between end customers and research-intensive suppliers. Manufacturers of machinery often have to develop new products on the basis of the perceived needs of end customers, but this can be avoided by building a strong network among producers of intermediary products:

> 'We are often the connecting link between the desires of our customers and the work of our suppliers [of machinery].' (Head of Production, Danish fabricated metal firm)

LMT firms can in this way collect valuable information, which is costly or even unattainable for high-tech firms, that allows the identification of new commercial possibilities throughout the value chain.

Innovative collaborations between high- and low-tech firms are in this way becoming increasingly widespread. It is therefore not surprising that it is stressed by our interviewees that one of the greatest disadvantages of the UK fabricated metal sector is the decline in the UK of the machinery industry, which is of vital importance for the diffusion of R&D:

> 'The UK metal industry has lost its machine makers and therefore finds it more difficult than previously to

> undertake many types of innovation projects. Today, a lot of the R&D knowledge in those areas is gone.' (Director, UK industrial organization)

This exemplifies the value of a mixed industrial environment that enables firms to benefit from different modes of innovation. In line with this, it was often stressed in the interviews that geographical proximity was extremely important in specific stages of the high-/low-tech collaborations, especially the actual product design phase. A partnership between two firms from distant parts of Denmark was described as difficult, precisely because of the distance:

> 'It is difficult to work efficiently with them on constructing the parts when we cannot just drop by each other. We try to compensate by arranging full day meetings quite frequently where we use rapid prototyping, but the meetings are often too short or at the wrong moment in the process.' (Technical Director, Danish fabricated metal firm)

In this specific case, the LMT firm described the high-tech firm as 'the state of the art' within their field, but it nevertheless considered finding a new partner firm at a closer distance. Other LMT firms explicitly mentioned co-location with partner firms as an important asset in the development projects.

> 'We all have to be present when we do the testing – and we do many tests – so it only works since we are located so close to one another.' (Product Manager, Danish plastics firm)

Again, these observations highlight how innovations are produced in close collaboration between firms with very diverse knowledge bases, but they also emphasize the benefits of a varied industrial ecology –for both high-tech and low-tech firms. The rationale for high-tech firms to enter into product development projects with low-tech firms is often the low-tech firms' knowledge about materials and engineering techniques – their synthetic knowledge base. Our interviews show that physical co-presence is most often needed to access this knowledge. Thus, the interdependency of industries indicates that there are certain benefits associated with supporting a diverse industrial composition, including both high- and low-tech firms.

Discussion and conclusion

In this paper we have argued that a broader view of innovation is needed, including further emphasis on relations between low-tech and high-tech firms, to get a better understanding of long-term growth and regional development. Thus there should be a greater emphasis on the interconnectedness of industries rather than exaggerating the importance of R&D. Development since 1995 shows that the direct economic importance of high-tech industries is limited and stable, but still policy makers and many researchers continue to focus on research-intensive industries. The current policy priorities continue to be inspired by the linear model of innovation and they are, first, likely to have suboptimal effects in terms of growth stimulation owing to a lack of attention to a very large part of the economy and, secondly, liable to increase interregional inequality because they do not take the heterogeneity of regions in Europe into consideration.

It has previously been suggested that the pure form of the linear model of innovation encourages uneven development and a clear spatial division of labour – inter- as well as intra-nationally (Henry et al., 1995). Flows of value are shaped and governed by global inter- and intra-firm linkages of firms based in prosperous regions (Hadjimichalis and Hudson, 2007). By focusing strongly on R&D, policy programmes are biased towards large firms in core urban areas of the EU with cross-border contact networks. Thus, they lead to a strengthening of the R&D capacity of the most advanced regions as well as to industrial concentration in regions with a sufficient supply of skilled labour, information and business services (Amin and Tomaney, 1995; Markusen, 1996).

The inability of peripheral regions to compete for high-tech industries is the result of both the current industrial composition of these regions and a lack of a suitable institutional environment. Not all regions have the necessary entrepreneurial and social traditions and it is difficult to create these through policy initiatives (Amin and Thrift, 1994; Hudson, 1997). Furthermore, successful and well-endowed regions are seeking to shape the EU policy agenda in their favour, focusing on R&D and advanced manufacturing rather than interregional equality (Hudson, 1997). The analysis presented in this paper indicates that their effort has been successful.

In a series of case studies, Markusen (1996) shows how the compatibility of regional and industrial policies is often low, especially for industries with large agglomeration economies and economies of scale. Experiences from Brazil, Japan, South Korea and the USA show how policy shifts towards high-tech industries have in all instances been associated with the concentration of economic development in a limited number of urban centres. Regional policy has been subordinated to industrial policy, leading to a reinforcement of the advantages of prosperous regions. In terms of science policy there is also a coincidence of the interests of prosperous regions and national governments. Changes in the governance of science policy have not led to greater regional equality; on the contrary, resources are becoming more concentrated and 'only certain regions can succeed in the global race to become "science regions"' (Perry and May, 2007: 1047).

What we suggest as an alternative to the current policy agenda is a greater focus on stimulating cooperation between industries with high and low research intensity as a way of targeting interregional inequality. Establishing such a policy focus would allow the inclusion of firms and institutions from peripheral regions to a much larger extent than is the case today, where regional policy increasingly has to give way to (high-tech-focused) industrial policy and science policy. The attractiveness of this approach is also owing to the endogenous character of development, which does not depend on the ability of the peripheral regions to develop institutional structures similar to those found in prosperous urban agglomerations, as well as to the attention it pays to the importance of different industries in different parts of growth cycles (Lundquist et al., 2008).

A final issue worth reflecting upon is the importance of spatial distance between high- and low-tech firms engaged in collaborations. This constitutes an important direction of further enquiry as there is a need for a greater understanding of the character of relations between high- and low-tech firms. Questions remain about the potential for firms to engage in development and learning collaborations across industries and distance. An initial hypothesis might be that geographical proximity is of primary importance for such collaborations because relational proximity is assumed to be low between firms from very dissimilar industries. Gertler's work on collective learning by users and producers of advanced manufacturing technology and the importance of geographical and cultural proximity in facilitating such collaborations supports this theory (Gertler, 1995, 1996; Gertler and DiGiovanna, 1997). On the other hand, some low-tech firms in peripheral regions are capable of tapping into external knowledge flows through collaboration with research institutions and firms with higher technological intensity (Giuliani and Bell, 2005). Future research contributions ought to analyse the mechanisms facilitating these partnerships. Is the relational proximity greater than expected? Do low-tech firms gain access to R&D through subsidiaries in urban growth regions? Do high-tech firms access tacit and skill-intensive knowledge through branches in peripheral areas?

Irrespective of the outcome of such analyses, strengthening the relational proximity of high- and low-tech firms is an area of great importance. This paper also shows the necessity of challenging the foundations of policymaking to ensure that outdated understandings of industrial linkages (the linear model of innovation) give way to newer ones (e.g. the chain-linked model of innovation) offering greater theoretical insights. In the worst case, a continuing focus on R&D will result in a decline in European low-tech industries and the regions where these are concentrated. In the longer run it might also harm the development of high-tech industries if the most innovative low-tech industries are in other parts of the world, thus increasing the difficulty of establishing collaborations. Consequently, there are several reasons for implementing a more inclusive European industrial policy.

Notes

We thank Frank Hansen, Christine Skytt and two anonymous referees for their valuable and helpful comments. The usual disclaimer applies.

1 A notable exception from this plethora of high-tech-focused reports is the publication *Constructing Regional Advantage* prepared by a group of 11 European scholars (European Commission, 2006a). The report takes a balanced and inclusive view on innovation policy but it appears as if it has had little influence on the overall innovation policy promoted by the EU.
2 A third way in which high- and low-tech industries are connected is through the gradual increase in research intensity of some previously low-tech industries, e.g. the Norwegian solar cell industry (Hanson, 2008). Thanks to Arne Isaksen for drawing our attention to this.

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PAPER V

The Danish fabricated metal industry: A competitive medium-low-tech industry in a high-wage country

Teis Hansen

Abstract

This paper aims to contribute to the knowledge on innovation processes in low- and medium-low-tech industries. Today, industries characterised as high-tech are perceived to be central to economic development, as the research intensity shields them from competition from low-wage countries. This is less the case for low-tech industries, but their economic importance continues to be large, however. It is thus interesting to analyse how they manage to remain competitive.

The analysis focuses on a case study of the fabricated metal industry by identifying the innovation strategies followed by firms located in a part of Jutland, where this industry has experienced growth. It is found that the ability to create tailor-made solutions is central to the competitiveness of these medium-low-tech firms. Knowledge is thus highly important, yet in different ways than for high-tech industries. This illustrates the importance of industrial policies that take these differences into account.

Keywords

Innovation, low-tech, industrial development, Denmark, fabricated metal industry.

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Introduction

Spatial development strategies in industrialised countries increasingly emphasise the crucial character of production and diffusion of knowledge for the innovativeness of firms (Garofoli, 2002). Continuous innovations are seen as necessary to remain competitive in the present knowledge economy (Maskell & Malmberg, 1999). In most instances, attention focuses on a number of high-tech industries which are perceived as central to economic development. In the current financial crisis, high-tech industries are often considered as vital to economic recovery (Pisano & Shih, 2009), and the relationship between these industries and national competitiveness is the centre of much research (e.g. Newman et al., 2005). Consequently, more and more regions choose to focus on industries such as IT, biotech and nanotech. Attracting and supporting firms within these areas are viewed as strategies which are sensible in the long run, but it is also recognised by scholars that many regions simply do not have the characteristics needed to support economic development within these fields (Malecki, 2004). Still, policymakers give less attention to industries which are not as directly related to scientific research (Jacobson & Heanue, 2005). These industries are seen as more prone to competition from low-wage countries, even though their economic importance continues to be large and constant in most industrialised economies, including Denmark. Yet, the Danish government's industrial policy stresses the crucial importance of research and development (R&D) for economic development (The Danish Government, 2006). As a result, policymakers take relatively little notice of the needs of a large share of the economy.

The main aim of the paper is to contribute to the understanding of the ways innovation happens in these industries, which are often given less attention than their size justifies. The paper presents a case study of fabricated metal firms in the northern part of Jutland, Denmark. Analysing how low-tech industries manage to remain competitive in high-wage countries through different forms of innovation processes is of key importance for policymakers' abilities to provide the optimal framework conditions for such firms. Thus, the research question of the paper is:

> *How do Danish low-tech and medium-low-tech (LMT) industries innovate and remain competitive despite the wage disadvantage relative to other countries?*

Such knowledge makes it possible to structure the Danish business support system around the needs of low-tech firms and ensure that the educational system provides the students with the skills required. The paper finds that both issues are matters of concern today.

The paper is divided into five further sections. The subsequent section provides a theoretical basis for the analysis. It focuses on theories about innovation processes in industries which are not characterised as high-tech. The second section gives a brief overview of the economic importance of Danish LMT industries followed by a section characterising the fabricated metal industry. The case study is analysed in the fourth section, which constitutes the main part of the paper, while the final section presents a discussion of the results of the analysis, specifically in relation to government policy.

Innovation in LMT industries

The innovativeness of firms is crucial for economic development – especially in the present knowledge economy (Maskell & Malmberg, 1999). Knowledge on innovation processes is therefore of significant importance, but most studies focus on high-tech industries such as biotech (e.g. Liebeskind et al., 1996; Audretsch & Feldman, 2003; Cooke, 2004; Coenen et al., 2004; Moodysson & Jonsson, 2007), while LMT innovation processes are less well-described (Hirsch-Kreinsen, 2005).

Innovation in LMT industries rarely happens as a result of firms' investments in scientific research. This does not imply that these industries are less innovative, but rather that innovation happens in different ways. Innovation in LMT industries is primarily based on a synthetic knowledge base that utilises existing knowledge rather than creates completely new knowledge, while high-tech industries are characterised by an analytical knowledge base emphasising knowledge creation through the use of scientific methods and modelling (Asheim & Gertler, 2005; Asheim & Coenen, 2006). Naturally, many firms combine the two ideal types of knowledge bases, and Jensen et al. (2007) actually find that such firms tend to be more innovative than firms relying on only one of the two knowledge bases. This contribution shows how the Science, Technology and Innovation (STI) mode (associated with the analytical knowledge base) and the Doing, Using and Interacting (DUI) mode (associated with the synthetic knowledge base) complement each other: experiences and practical knowledge are most often essential for scientists working in R&D departments of high-tech firms when designing research projects and interpreting results, and in the same way, scientific knowledge can often be part of the solution for firms which otherwise emphasise learning-by-doing and learning-by-using. Accordingly, the STI and DUI modes are not completely dependent on the analytical and synthetic knowledge base, respectively, but include elements from both (Asheim, 2009).

In accordance with Jensen et al. (2007), Lorenz & Valeyre (2006) observe a clear correlation between a high rate of technological innovation and an organisational form promoting high individual responsibility and common problem solving, which is typical of the DUI mode. Promoting interactive learning at the workplace is therefore of significant importance for all types of firms (Arundel et al., 2007), but it is of particular importance for LMT industries, which primarily depend on a synthetic knowledge base. This is, to a high degree, founded on the transformative and configurational capabilities of the workforce (Bender & Laestadius, 2005).

Transformative capabilities allow firms to convert global knowledge, which is available worldwide, to knowledge which is specific to a certain context. Such local knowledge is always tacit to some extent, while global knowledge is codified. The transformative capability is thus to combine the general knowledge with practical knowledge about the specific locality. This does not result in completely new products or processes, but rather in local versions of products or processes that are generally known. Innovation thus results from the ability to create such local solutions (ibid., 2005).

Configurational capabilities make it possible for firms to synthesise novelties by organising knowledge, artefacts and actors in new ways. The authors point out three different aspects of these capabilities. Firstly, such capabilities arise from the capacity to combine knowledge from different areas in new ways. The exact combination of knowledge – codified or tacit, scientific or practical, held by individuals or teams – may vary, but the timing and speed of this creativity are crucial. The ability to create or predict future demands is of great value to firms. Secondly, combining different types of knowledge often involves cooperation with external actors. The ability to organise such cooperations, which makes the necessary knowledge available, is therefore also essential. This is especially the case for smaller companies which often do not have the resources to hire the necessary staff, and active participation in the local economy is therefore correlated with innovation capacity for LMT firms (Petrou & Daskalopoulou, 2009). Thus, up-to-date knowledge about potential partners is important for these firms. The third aspect concerns the design of specific solutions which can be described as the ability to convert this combined knowledge into products or processes that fulfil specific needs. That this ability has been important for firms in general has been overlooked (Walsh, 1996), but it is imperative for LMT firms (Santamaría et al., 2009).

However, this distinction between transformative and configurational capabilities is fundamentally analytical, and it is empirically difficult to separate the two dimensions (Hirsch-Kreinsen et al., 2006). Nevertheless, it is very useful to be aware of the different capabilities which are important for the innovative abilities of LMT firms, as these underpin the different innovation strategies available to the firms (Hirsch-Kreinsen, 2008).

LMT innovation strategies

The first of these innovation strategies is termed *step-by-step*. It is based on a continuous improvement of the product produced, and the general attributes of the product thus evolve slowly. This strategy is especially followed by firms producing goods with relatively low fluctuations in demand. Capabilities that allow firms to take up and transform knowledge already available in the specific context are central to this strategy.

A second innovation strategy is *orientated towards the customers*. This strategy is primarily based on the configurational capabilities. Combining existing knowledge in new ways creates new products or production processes, and customers often act as innovation stimulators as well as testers of new products (Fagerberg, 1995). Moreover, in some instances, customers can also act as technology agents by providing LMT firms with knowledge on the products and technologies used by competitors (Chen, 2009). Firms in many different industries use the customer-oriented strategy, and it is generally becoming more important for firms to be aware of the market demands, especially of key customers (Hansen & Serin, 1997; Mendonça, 2009).

Finally, Hirsch-Kreinsen (2008) describes *process specialisations*. This innovation strategy is mostly carried out in firms which are producing goods involving a relatively high degree of automation, e.g. the food processing industry. In this case, innovation depends on capabilities which make it possible to combine new knowledge with the practical knowledge specific to the individual firm and production process. Especially this innovation strategy involves the participation of all employees in the innovation process. Firms pursuing this strategy therefore employ people who have traditional technical skills as well as competencies related to new technologies. Heidenreich (2009) confirms the importance of this type of innovation for the development of LMT firms, as 36% reports process innovations over a three year period (CIS4, 2002-2004) compared to 17% of high- and medium-high-tech firms. Furthermore, Kirner et al. (2009) finds that the quality of products made by low-tech firms is superior, which indicates that these firms give more attention to the fine-tuning of production processes than firms with high R&D intensity.

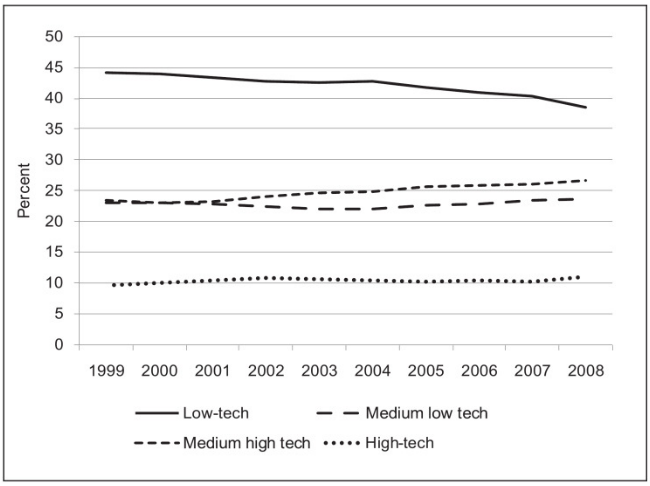
To sum up, there is a great difference between the ways knowledge is used in the innovation processes in the LMT sector compared to the high-tech sector. This is due to the fact that high-tech innovations are much more focused on the actual role of technology. LMT firms are using technology, while high-tech firms are selling technology (von Tunzelmann & Acha, 2005). However, even though this is the general picture, it is not always the case. Mendonça (2009) as well as Robertson & Patel (2005) show how firms from LMT industries increasingly patent their products within high-tech areas. LMT firms are thus integrating and diversifying into e.g. biotech, information and communication technology (ICT) and new materials. Subsequently, high-tech knowledge is increasingly becoming important for innovation in LMT industries.

Danish LMT industries

One of the Danish government's goals is to promote Denmark as a leading knowledge-society (The Danish Government, 2007). This is also very evident in the government's Globalisation Strategy where the two main foci are education and innovation (The Danish Government, 2006). Even though issues related to user driven innovation are considered in the strategy, most attention is given to the importance of R&D for the innovative capacity of firms.

Still, figures from the OECD's STAN database show that the low-tech sector continues to constitute approximately 35% of Danish exports (2006). Furthermore, Figure

Figure 1: Shares of employment in total Danish manufacturing, 1999-2008.



Source: Own elaboration on the basis of figures from Statistics Denmark (RAS9).

1 shows the shares of employment in total manufacturing according to R&D intensity, and it is seen that low-tech industries are also hugely important in these terms.

The figure shows that the shares have actually changed over the last ten years; however, the change cannot be characterised as dramatic in any way. The employment in the low-tech sector continues to be by far the greatest, even though it has decreased approximately 6% over the period. Moreover, the share of low-tech employment is still substantially larger in Denmark than in a sample of eleven OECD countries (Kaloudis et al., 2005). The Danish 1999 share of low-tech employment at 44% is approximately 10% larger than the equivalent 1999 share in the eleven OECD countries. The decrease in the share of Danish low-tech employment to around 38% in 2007 should therefore be seen as a development towards the OECD average, which was at 35% at the end of the data series (1999) presented by Kaloudis et al. (2005).

These figures illustrate the continuing importance of industries with low R&D intensity for Danish economy. One of these industries is fabricated metal, which is the third most important Danish industry in terms of employment with a workforce of more than 42,000 (2008), equivalent to 10.4% of manufacturing employment. The following section depicts the development of this industry over the period 1993-2006.

The Danish fabricated metal industry

The fabricated metal industry encompasses the production of pure metal products without moving parts such as tanks, steam kettles, cutlery, hand tools, fittings, bolts, nails and cans. Furthermore, it also includes such metal processing as moulding, welding and coating (Statistics Denmark, 2002). It is interesting to note that very little has been written about the Danish fabricated metal industry despite its large economic importance. Only few of the niches within the industry have been analysed:

- Christensen & Munksgaard (2001) analyse the stainless steel cluster in the Triangle Region, which is characterised by dense input-output relations. There are many small and medium-sized enterprises (SMEs) within the area, but they are seldom involved in innovative projects by the few important end-producers that dominate the inter-firm relationships.
- The work by Hansen & Serin (1999; 2000) is focusing on metal packaging. This niche has been characterised by specialisation and acquisitions since its establishment in the 1920s, and the development has been more closely connected to the success of the Danish food manufacturing industry rather than to the innovative capabilities of the firms.

Besides these contributions, the development of the fabricated metal industry has so far been of little interest to Danish scholars. One aspect is, however, clear: outsourcing is a significant process in the industry. 30% of all Danish iron and metal firms outsourced to low-wage countries from 2001 to 2004 (Hansen & Mortensen, 2006). The reason for this is the intensifying international competition, which makes it necessary to outsource the labour intensive parts of production processes to low-wage East-Asian countries. This led to a decrease in the number of especially smaller metal firms during the 1990s (Danish Business Promotion Office, 2001). The manufacturing of complicated metal goods and/or batches of limited size has, however, been kept in Denmark to a large extent (Jørgensen & Banff, 2004).

The industry's skill level has been characterised by a decline in the share of employees with primary education, which, to a large extent, corresponds to the increase in personnel with vocational education (Table 1). The share of employees with vocational education is the second largest of all Danish industries, only surpassed by manufacturing of other transport equipment.

Table 2 shows that the employment of the industry has

Table 1: Highest education level attained by employees in the fabricated metal industry.

	1993	1996	2002	2004	2006
Primary school	39.4%	38.1%	32.8%	31.5%	31.0%
Ordinary secondary school	1.6%	1.8%	1.9%	1.8%	1.7%
Technical secondary school	1.2%	1.3%	1.4%	1.3%	1.5%
Vocational education	47.5%	48.0%	52.2%	53.0%	53.2%
Short further education	3.2%	3.4%	4.4%	4.8%	4.9%
Medium-long further education	3.5%	3.8%	4.1%	4.2%	4.3%
Bachelor degree	0.2%	0.3%	0.3%	0.4%	0.4%
Long further education	0.5%	0.7%	0.8%	0.9%	1.0%
Scientist	0.0%	0.0%	0.0%	0.0%	0.0%
Unknown	2.8%	2.5%	2.1%	2.0%	2.0%

Source: Own elaboration on the basis of figures from Statistics Denmark (RAS9).

been moderately declining since 1996, particularly in the urban municipalities (containing a city with more than 40,000 inhabitants), where the decline accelerated at the end of the period. The rural municipalities (all towns have less than 10,000 inhabitants) have, on the other hand, maintained a relatively constant employment. The relocation process of the fabricated metal industry, which took place in the 1970s and 1980s from the greater Copenhagen area to especially the peripheral parts of Jutland (Winther, 1996; Kristensen, 1999), thus seems to be continuing, however at a slower pace.

Still, the fabricated metal industry continues to remain competitive. The development from 1990 to 2006 of the industry's value added and labour productivity (defined as value added per working hour) is compared to the similar development of the total Danish economy in Figure 2. In terms of value added, the increase of the fabricated metal industry was above the total economy's increase throughout the 1990s, but the index values were similar during the last two years of the period. With respect to labour productivity, it is interesting to see that the index values of the fabricated metal industry have been constantly higher than the corresponding values of the total economy. These findings confirm that the industry develops in a way which is at least as positive as the development of the Danish economy as a whole.

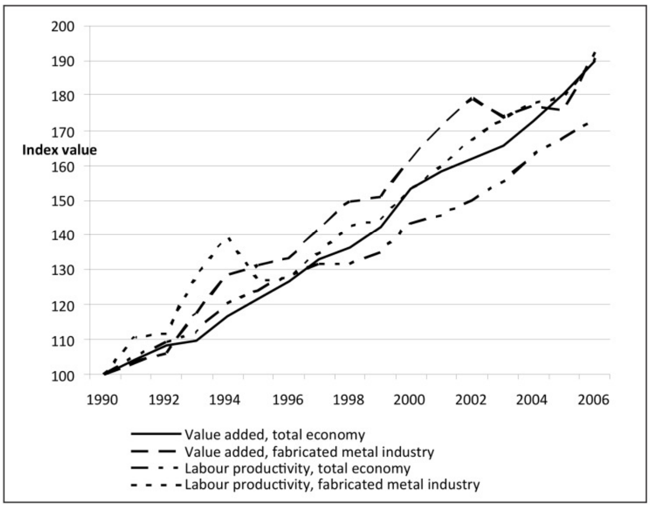
One of the regions where the fabricated metal industry has been performing well in the period 1993-2006 is an area in the northern part of Jutland from Brønderslev and Dronninglund in the north to Bjerringbro in the south. The municipalities which make up this area are characterised by a high concentration of fabricated metal employment relative to the rest of Denmark, and furthermore, they have increased this concentration over the analysed

Table 2: Fabricated metal employment according to municipality characteristics.

	1993	1996	2002	2004	2006	Δ 1993-2002 in %/year	Δ 2002-2006 in %/year
Urban	17,119	16,724	15,616	14,437	14,118	-1.0	-2.4
Intermediate	11,764	12,134	10,733	10,571	9,939	-1.0	-1.8
Rural	17,853	18,981	19,172	18,122	18,670	0.8	-0.7
Total	46,736	47,839	45,521	43,130	42,727	-0.3	-1.5

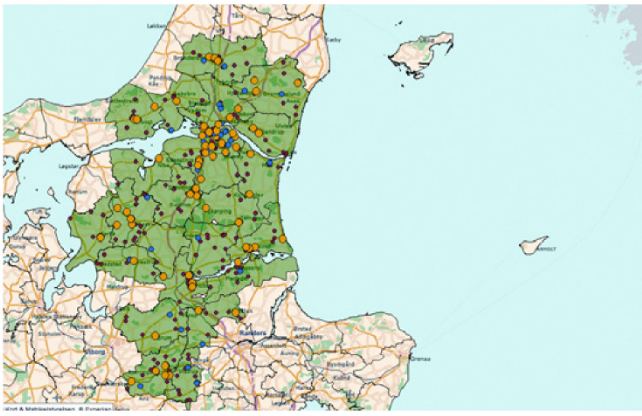
Source: Statistics Denmark (RAS-database).

Figure 2: *Development of value added and labour productivity (current prices), 1990 = index 100.*



Source: Own elaboration on the basis of figures from Statistics Denmark (NATE1301 and NATE1304).

Figure 3: *The case study area.*
Small dots: *< 5 employees – Medium dots: 5-19 employees – Large dots: > 20 employees*



Source: Own elaboration on the basis of data from Experian. Map copyrights: Kort & Matrikelstyrelsen.

period. Finally, the municipalities have also performed better than the fabricated metal industries in a European peer group consisting of Finland, France, Germany, Sweden and the United Kingdom, which indicates that the international competitiveness of the area is also improving. A detailed description of the methodology and results of this quantitative analysis can be found in Hansen (2009), but it will not be included here, as this paper focuses on the qualitative analysis of the innovation strategies utilised by firms in this area. The subsequent section will thus seek to clarify the innovation strategies which lie behind the positive development of the area's fabricated metal industry. The analysis is based on 20 interviews with key actors from firms, educational institutions and industrial organisations. The firms are selected so that SMEs as well as large firms are included in the analysis in addition to both firms focusing on exports and domestic markets.

Innovation strategies in the fabricated metal industry

The case study area consists of 15 municipalities (according to the 2006 administrative structure) shown in Figure 3. The importance of overall industrial activity for employment is very different among the municipalities – the share of industrial employment varies between 6% and 30%. Thus the area cannot be described as a traditional industrial district like e.g. the Herning-Ringkøbing area, where a concentration of fabricated metal firms is also found (Hansen, 2009).

The dots on the map show how the 414 fabricated metal firms are spread out over the area. 160 of the firms have five or more employees, while 82 firms have at least 20 employees. Concentrations are found around the cities of Aalborg, Hobro, Hadsund, Brønderslev and Bjerringbro.

Innovation strategies

The interviews very clearly confirm the great importance of transformative and configurational capabilities for the innovation processes in the case study area's fabricated metal firms. The majority of the firms primarily rely on a synthetic knowledge base, and the three different innovation strategies described by Hirsch-Kreinsen (2008) are widely used and combined by the firms.

The *step-by-step* strategy is the least prominent innovation strategy among the three, even though it is still of major importance for some of the firms. One example is a firm producing metal products which meets the high surface-quality requirements of e.g. some of the most renowned Danish furniture firms. Surface technology is a field where very few radical innovations take place today, but the firm continuously improves the surface quality of the products in order to maintain its position as a preferred sub-supplier to high quality furniture producers. A second example is a producer of combustion plants mainly used for bio fuel. The fundamental technology is also well-known within this subject, and the firm's competitiveness thus mainly depends on the ability to reduce the plants' emissions.

Therefore, innovations for this firm are closely related to a continuous improvement of the product.

The strategy *oriented towards the customers* is by far the most widespread, and all the firms interviewed follow this strategy to a greater or lesser extent. Customer relations are thus very important as emphasised by both Hansen & Serin (1997) and Mendonça (2009), and the interviews furthermore underline that close customer relations are getting increasingly important for a majority of the firms.

The ways in which the firms use this innovation strategy are, however, quite different both in relation to the frequency and the mode of contact to the customer. Some firms constantly interact with their customers, while others have more seldom contact. Similarly, face-to-face meetings with customers are very important for some firms, while contact by email or phone is sufficient for others. These differences primarily depend on the complexity of the products and the derived needs for transferring information and knowledge between customer and producer.

Customisation of products generates nearly the entire turnover for a number of the fabricated metal firms. This is e.g. the case for a firm which is the world leading producer of concrete pipe machines. All products are either unique or produced in a very low volume. A second example is a firm working with processes such as enamelling, polishing and welding. For this firm, 75% of the turnover is created through the production of customised products, which demands frequent exchange of information with the customers. Yet another example is a manufacturer of stainless steel tanks. This firm only reproduces a previously manufactured tank if a customer needs to have an order repeated, and the batches are furthermore small, typically 1-3 tanks. The contact with the customer is thus very frequent in order to agree on the exact specifications of each individual product:

> *"Drawings can be exchanged up to 20 or 30 times before the initiation of production if the product is of great complexity."*
>
> Head of Production, small firm

This underlines the significance of co-operation between firms and their customers, especially in regard to the manufacturing of tailor-made products.

However, the production of customised products does not constitute the majority of the turnover for all the firms interviewed. This can be due to two reasons. Firstly, simple goods can continue to be important in the production line, even though this was only the case for one firm offering a number of metal working processes. 80% of the orders of this firm are of such standard character, while the remaining 20% has to be customised, typically as they are part of other products. Secondly, innovations which contain a more radical element were found to be important in a few cases. One example is a firm which is among the leading in the world within the production of stainless steel feet to machines. Although the development of customer-specific solutions is somewhat important, it is the more radical innovations that are at the core of the firm's business model. Technological progress, within CAD/CAM as well as the improved access to information about products and standards on the internet, has implied that it is becoming increasingly possible for an SME like this firm to engage in such radical innovations. A second prime example is an R&D intensive producer of metal powder and stainless steel products. Two out of three innovations carried out in this firm can be characterised as radical innovations which are basically founded on the ideas and research carried out by the staff. Yet, the relations to customers are still important: the remaining third of the innovations is based on specific customer needs, and the firm has furthermore learned that it is essential to analyse the commercial interest of the radical innovations at an early stage. The firm had a number of previous experiences, where a brilliant new product was a failure, as there was no market for it. This exemplifies the importance of combining the STI mode (research in powder technologies) and the DUI mode (interacting with customers) in order to promote growth at the firm level (Jensen et al., 2007).

The interviews do not indicate that it is primarily the smaller firms that emphasise customer-oriented innovation processes. One of the largest participants in the analysis is a factory producing fittings. Even though manufacturing of standard products is still important for the firm, it is worth noticing that innovation processes are increasingly being led by customer demand, and that customers are involved in nine out of ten new product developments. This emphasises that the technology pull originating from the customers is of great importance even for the largest fabricated metal firms with their own development department.

Finally, innovations through *process specialisation* are also of key importance for the competitiveness of a number of firms – both large and small. Among the large firms is a producer of great steel structures. A crucial area of innovation for this firm is automation of welding processes, which yields great returns due to the scale of the structures constructed. Optimisation of the production methods is for instance imperative in the manufacturing of foundations for offshore windmills. Another example is a firm to which the fine-tuning of casting processes is central to innovations. The technology of casting is well-known, and few ground-breaking advances are made today. However, this firm develops and builds machinery that allows it to improve the accuracy of the casting process and thereby achieve higher uniformity in the final products. This keeps the need for additional modifications of goods at a minimum.

Improvement of production processes can also be important for other reasons than simply reducing production costs. Developing the quality and the range of services offered is highly important for one of the firms to get access to new markets. Large, potential customers like Deutsche Bahn constantly introduce new requirements and standards that the suppliers must meet. A continuous improvement and certification of skills and capabilities is therefore necessary in order to include and maintain the most attractive customers in the clientele.

The importance of customer and supplier relations for innovation

The previous section underlined the relevance of the innovation strategies defined by Hirsch-Kreinsen (2008) in relation to the fabricated metal firms in the case study area. The customer-oriented strategy was especially widespread, and customisation of products is of major importance for firms irrespective of size. Naturally, customisation occurs differently and the levels of technology are utilised in different ways by the firms, but the process is fundamentally the same: the firms' ability to create and implement solutions to specific needs – often in cooperation with the customers – is essential to the survival of many firms. Close relations to customers are thus of significant importance. The remaining part of this section will focus on linkages to suppliers, as customer linkages were described in detail above.

An innovation strategy closely related to process specialisation, but not directly included as it is defined by Hirsch-Kreinsen (2008), is to purchase capital goods with inbuilt R&D. Firms thereby indirectly benefit from R&D, but they also indirectly pay for it. Use of advanced machinery has previously been identified as an important source of innovation for LMT firms in several studies (Santamaría et al., 2009; Heidenreich, 2009), and buying machinery from suppliers is also central to the innovation strategies of a considerable number of firms in this survey. This is primarily the case for smaller firms which do not produce any final goods and therefore exclusively work as suppliers. Acquiring the right machinery is absolutely fundamental for these firms, since it may save both time and manpower as well as improve the quality of the work. However, it was emphasised on several instances during the interviews that it becomes increasingly difficult to have an overview of the possibilities offered by the market.

> *"Both the number of models and the complexity of the machines have increased rapidly during the last years."*
> Managing Director, medium sized firm

This highlights the importance of acquiring analytical knowledge for firms with a mainly synthetic knowledge base (Jensen et al., 2007). The ability to match the firm's needs with the opportunities provided by the market is essential, but it demands considerable technological knowledge.

The fabricated metal firms in the case study area also involve suppliers of innovation processes by forming more or less formalised strategic alliances. Most of these cooperations are informal in the sense that many firms have preferred suppliers whom they trust and have frequent contact with. These firms are chosen due to their flexibility, price and the quality of their products as well as the product equipment they use. Some firms share clientele as they recommend each other to customers when possible. Contact between the firms and the suppliers is very frequent – in some instances daily – in order to coordinate the production processes and agree on issues such as tolerances and choice of materials. The cooperation between firms may develop even further than such informal partnership. One firm has gone as far as signing development contracts with its closest suppliers, which gives the firm exclusive rights to the products or at least advantageous conditions. Consequently, the suppliers are functioning as an ad hoc pool of development staff.

A further way of involving supplier relationships in innovation processes is through outsourcing. The large wage differences between Denmark and Eastern European and especially Asian countries imply that there are large potential benefits related to outsourcing. Realising these potentials can, however, be troublesome due to difficulties associated with language, culture and geographical distance. One of the largest firms thus describes its ability to manage outsourcing as essential to its innovation processes. The experiences gained by the firm through outsourcing to Poland and Turkey are now used in China, and some of the firm's Polish employees have been heavily involved in order to contribute with their perspectives on potential pitfalls.

Competition from low-wage countries
The outsourcing strategy of the firm described above is typical of the low-wage countries' impact on the competitiveness of Danish firms: manufacturing of large structures takes place in e.g. China, while completion and assembling of different parts in addition to manufacturing of smaller goods continue to be placed in Denmark. This pattern also emerges in a number of other interviews. One example is a casting firm which produced batches of up to 500,000 similar pieces to the German auto manufacturing industry in the 1990s, but the production of such simple castings has now been relocated. Another example is a factory producing fittings which is under growing competitive pressure concerning the production of large batches. Therefore, both firms increasingly emphasise manufacturing smaller batches of high quality. An example from the fitting factory is the production of 20 copies of fittings from 1878 used in a recent renovation of Amalienborg, the Danish royal palace.

Despite the competition from low-wage countries, the interviews show that the clear majority of firms do not consider this competition as threatening to their existence; several firms experience that former customers return after having used suppliers in low-wage countries for a while. One of the most important problems associated with sourcing from low-wage countries is that the quality of the products does not reach Danish standards:

> *"The product quality is often high in the first shipment, average in the second shipment and then strikingly lower from the third shipment."*
>
> Head of Development, small firm

A second problem is the terms, conditions and transaction costs related to production in e.g. China. Usually a Danish firm will pay one third of the price before production starts and the remaining two thirds when the products are shipped off. Total production and delivery time is typically 3-4 months. It was stated in several of the interviews that Danish firms will often be able to produce as cheaply as their Chinese competitors if they are given the same conditions.

A third issue is the need for face-to-face interaction between customers and suppliers. As described previously, most of the fabricated metal firms have very close contact with their customers. This reflects that the majority of the firms have now evolved into producers of higher-ordered goods, which is less footloose than the production of large standardised batches. Communication by phone and email is therefore insufficient, especially considering the language differences. This barrier – as well as the other issues – shields the Danish firms against low-wage competition.

Increasing knowledge content – securing continuing competitiveness
The continuing competitiveness of the Danish fabricated metal industry is very closely related to the firms' ability to increase the knowledge content in their products. Profiting from especially the tacit knowledge held by employees is a necessity in order to continue the development of unique attributes which cannot easily be transferred across geographical distance. The case study has highlighted two different issues which make it difficult for the firms to develop their business in a more knowledge intensive direction:

Questions on *intellectual property rights* come along with the increasing knowledge intensity of products, even when they are primarily based on tacit knowledge. Tacit knowledge is fundamental for most innovation processes in the fabricated metal industry, but the replicability of metal products is still high once they are developed and disseminated. The protection of products through patents is thus increasingly relevant for fabricated metal firms. It is therefore problematic that the patenting system is fundamentally focused on high-tech industries and radical innovations, while incremental innovations which are typical of the fabricated metal industry do not qualify for patents. It is thus stated as a direct requirement that:

> *"The invention must differentiate itself significantly from the known techniques on the field."*
>
> Danish Patent and Trademark Office, 2008, p. 1

Consequently, many fabricated metal firms have to protect their products through alternative methods. One example is a firm which does not advertise newly developed products. No information about the products can be found on the firm's webpage, and they are only presented to selected customers who are allowed to purchase them. Another firm benefits from the fact that all material describing the techniques used by the firm is written in Danish and thus hardly accessible for its competitors, who are mainly Japanese.

Even though such strategies may be very effective for the individual firm, they are not optimal or replicable in every case. The mismatch between the patenting system and the innovation strategies of firms working on the basis of a synthetic knowledge base is therefore an important issue to deal with, especially as the knowledge content – and the value of the products – increases.

A second, very important issue is related to the *skill-level of the workforce* in the fabricated metal industry. Successful LMT firms invest in high levels of training for all staff (Corbett, 2008), as the development towards production of goods with increasing knowledge content depends completely on firms' ability to access a sufficiently skilled workforce. At the time of the interviews (January and February 2009), the majority of the firms did not have problems recruiting the necessary labour, but almost all of them had such problems before the start of the current financial crisis, resulting in reduced growth rates. A main reason for this appears to be the inability of the educational institutions to provide the students with a sufficiently high level of skills, thus limiting the possibilities for firms to introduce elements from the STI mode in their production processes (Jensen et al., 2007). The problem for institutions offering vocational education is that trades such as smith or welder do not attract the youth with academic abilities, while the fabricated metal firms are increasingly seeking employees with both academic and practical skills. The educational institutions therefore face a dilemma:

- Shall they maintain the current degree of difficulty even though it does not fit the needs of the firms?
- Or shall they increase the degree of difficulty even though a large proportion of the students will not be able to fulfil the demands?

Unfortunately, this dilemma appears to have no easy solution. One vocational school in the region has increased the degree of difficulty, resulting in an increase in the number of failing students. Similarly, another vocational school introduced a new education in metal work targeting the energy sector, but it failed to attract students; presumably due to the relatively large amount of academic content. Thus the education was not established even though firms are seeking employees with this knowledge combination. This clarifies why most of the firms have considerable difficulties getting access to qualified labour during normal economic conditions.

A second problem for the educational institutions is related to the growing capital intensity of the fabricated metal industry. The ability of employees to operate machinery is absolutely essential for the firms' productivity. However, the rapid development of new equipment combined with their increasing sophistication and preciousness imply that the educational institutions are unable to keep up with firms' investments in machinery. This is reflected in the great emphasis that employers place on upgrading of skills and training on the job. A number of firms actually prefer to train the workers themselves. One phrased it in this way:

> *"Formal education does not have great importance – it can actually be an advantage not to hire someone who has previously been working on a specific machine and who carries with him old habits and routines."*
>
> Managing Director, medium sized firms

These firms stress the importance of characteristics such as flexibility, willingness to learn and a sense of quality rather than the applicants' formal education. It should, however, be noted that a group of other firms emphasise the formal education and only hire people with relevant degrees.

The case study area – localised advantages?

When searching for an explanation for the success of the fabricated metal industry in the case study area, it is first of all relevant to compare the skill-level of the employees with the national average, given the increasing importance of knowledge content in the products of the industry. However, the skill-level in the case study area (Table 3) is quite similar to the average of the Danish fabricated metal industry (Table 1), even though the share constituted by employees with further education is a bit higher in the case study area. The main difference is with regard to 'Long further education', which constitutes respectively 1.8% and 1.0% in the two areas.

Thus, the education level of the employees does not explain the positive development in the area. This is, however, not surprising considering the problems of the educational institutions described above. Instead, a number of other features underlined in the interviews appear to be more important.

It is expected that the geographical distance to customers is of great importance to the industry, considering the significance of the innovation strategy that is based on customisation. A number of firms note that the existence of a large pool of customers in the area within the fabricated metal and related industries is crucial. Furthermore, the effect of the location of large firms in the area – especially Grundfos – is also put forward on several occasions. Some firms, however, also consider the distance to the Triangle Region in the Southern part of Jutland as a disadvantage.

The characteristics of the local labour market also appear to be beneficial for the firms in the case study area. The concentration of metal firms in the area implies that the number of potential employees is high, and people are less

Table 3: *Highest education level attained by employees in the fabricated metal industry (case study area).*

	1993	1996	2002	2004	2006
Primary school	37.2%	37.2%	31.8%	31.3%	30.2%
Ordinary secondary school	1.5%	1.6%	1.9%	1.8%	1.6%
Technical secondary school	1.4%	1.5%	1.6%	1.4%	1.7%
Vocational education	45.8%	48.3%	50.7%	51.5%	52.3%
Short further education	4.6%	3.8%	5.4%	5.6%	5.8%
Medium-long further education	5.9%	4.3%	4.8%	4.8%	4.4%
Bachelor degree	0.4%	0.4%	0.4%	0.5%	0.4%
Long further education	1.0%	1.0%	1.5%	1.6%	1.8%
Scientist	0.0%	0.0%	0.1%	0.1%	0.1%
Unknown	2.1%	2.0%	1.9%	1.4%	1.7%

Source: Own elaboration on the basis of figures from Statistics Denmark (RAS9).

hesitant to work in noisy and dirty jobs than elsewhere. The firms thus benefit from a shared pool of labour, as described by Marshall (1890). Furthermore, the wage-level is also an advantage for the firms. The average wage-level in the North Denmark Region – which covers the main part of the case study area – is the lowest of the five Danish regions. Finally, the characteristics of the area's labour force are highly valued by a representative of one of the larger firms. Interestingly, this is not linked with the formal education in the area. Instead, the flexibility and the technical capabilities of the workforce are associated with the rurality of the region. Overall, the availability of a relatively cheap and large labour force with a traditional focus on practical skills and flexibility hence appears to be one of the assets of the fabricated metal industry in the case study area.

Tradition and the characteristics of the workforce also influence the entrepreneurial spirit, which seems to be highly valued in the area. It was stated by managing directors on several instances during the interviews that the growth of their businesses is their personal responsibility, and they do not expect the government to provide much help.

> *"It is a point of honour for me to have a healthy firm which minds its own business."*
>
> Managing Director, medium sized firm

This professional pride is also reflected in the weight given to the manufacturing of quality products. The extent to which the firms emphasise this aspect is interesting to note. Nearly all 17 firms were described as producers of quality goods, and eight of the firms were directly described as differentiating themselves from other Danish firms by their emphasis on quality.

> *"One of the main strengths of this firm is the emphasis on quality – our prices are quite high, but it pays off."*
>
> Head of Department, medium sized firm

This trade-off between quality and price is found in a number of other firms. It is notable the extent to which this issue is underlined in the interviews, even though it should be taken into consideration that managers are likely to have a biased opinion with respect to the quality level of their products.

Summing up, the analysis shows that the existence of a large local market and the presence of a high number of metal workers with a tradition for physical and practical work, combined with an independent and quality-focused attitude are of main importance in order to explain the development of the fabricated metal industry in the case study area. Conversely, contact to knowledge institutions as well as governmental programs and initiatives have, at best, a marginal importance for the majority of the firms. These issues will be considered in the concluding discussion.

Room for LMT industries in Denmark? Discussion and conclusion

The analysis presented in this paper underlines that the size and economic importance of LMT industries is substantial and stable. The analysis furthermore clarifies the ways in which LMT firms innovate and remain competitive in a globalised economy. The recipe is founded on a clever exploitation and development of the synthetic knowledge base in the firms. This knowledge base enables undertaking a number of different innovation strategies, which are essential in the efforts to fight off competition from low-wage countries. Despite this, most political interest is still directed towards high-tech industries (see e.g. Hirsch-Kreinsen, 2005; Jacobson & Heanue, 2005;Turok, 2004), which are seen as representing the future of economic activity in the western world. Recently, more inclusive views on innovation, which consider the DUI mode of innovation, have, however, been promoted by some policy makers. An example of this is the national innovation strategy adopted by the Finnish government in 2008 (Finnish Council of State, 2008), which recognises that innovation policies have so far exaggerated the focus on development and commercialisation of new technologies. The strategy furthermore specifically emphasises the need for a *broad-based innovation strategy* that also encompasses a significant orientation towards the demand of customers, even though a recently prepared evaluation criticises the impreciseness of the notion and the mechanisms whereby such a broad based innovation strategy shall be achieved (Edquist et al., 2009). Similarly, a policy report published by the European Commission highlights the necessity of recognising the different knowledge bases of firms and not solely preparing policies targeting firms with an analytical knowledge base, as *"knowledge and innovation should not simply be equated with R&D"* (European Commission, 2006, p. 25).

Still, other EU publications continue to stress the overwhelming importance of R&D. Recent examples include the innovation scoreboards (see Hollanders et al., 2009; Jensen et al., 2007) and the process of producing indicators for monitoring the development of the European Research Area, where it is evident that a knowledge-based economy is considered very closely linked to the significance of R&D (European Commission, 2009).

To a large extent, the overwhelming policy focus on high-tech industries can also be found in the interest in academia, even though some research centres take a broader view on innovation, e.g. UNU-MERIT (see for instance Arundel & Kemp, 2009; Goedhuys et al., 2008) and the institutions involved in the EU funded PILOT (Policy and Innovation in Low-tech) project (Hirsch-Kreinsen et al., 2006). Still, these studies are hardly comparable in numbers to the numerous studies of high-tech sectors, such as biotech and ICT, which are constantly carried out. The problem is not the amount of these papers – the problem is that studies of LMT industries are much scarcer. Ignoring these industries will eventually reduce the concept of innovation to only encompass the types of innovations which take place in high-tech industries. This will further increase the focus on promoting conditions for firms working from an analytical knowledge base and reinforce the imbalanced attention given by politicians to high-tech industries. An important consequence is that little consideration is given to the development of peripheral and rural regions, which are unable to attract these R&D intensive industries.

This paper demonstrates that such focus on high-tech industries is flawed, as it ignores the huge importance and potential of LMT industries even in a high-wage country as Denmark. This is mirrored in the interviews carried out for this project, where dissatisfaction with the Danish government's policies towards the fabricated metal industry is prevalent. The feeling among most firms is that they have to look after themselves:

> *"The growth taking place in fabricated metal firms is solely due to the firms themselves. There are many other trades and industries which are more eye-catching than the fabricated metal industry."*
>
> Head of Production, small firm

In this way, the competitiveness of the fabricated metal industry is not seen as a topic the politicians care about – at least not until the firms start firing people and the large economic importance of the industry becomes obvious. Based on the interviews, three key target areas for political action have been identified:

- Improve the quality and attractiveness of the relevant educations
- Promote cooperation between firms and knowledge institutions
- Introduce innovation policies targeting LMT innovation processes

The interviews clearly show that the most serious consequence of this attitude is linked to the skill-level of the workforce. The inability of the technical schools to provide the students with skills that satisfy the needs of the fabricated metal firms threatens the future supply of qualified labour. Increasing the attractiveness of the technical schools and the educations relevant for the fabricated metal industry should be a priority for the politicians. The main problem, which has so far been politically ignored, is the low prestige of these educations. Changing this situation demands action all the way down to elementary school where the foundations for these attitudes are laid, but it is interesting to note that the same mechanisms can also be found at the university level. The most R&D intensive firm included in the analysis thus has problems recruiting people with master degrees, as most students focus on biotech, nanotech and cleantech today. Thus *a key recommendation* on the basis of this analysis is that politicians should encourage students' interest in the fabricated metal industry, rather than treating it as if it has little future in Denmark. This will allow LMT firms to apply aspects of the STI mode in their production processes, following Jensen et al. (2007).

Related to the issue regarding the skill-level of the workforce is the importance of the knowledge institutions for the industry. The case study shows that there is very limited contact between the firms in the area and the local universities, even though quite a large share of the firms would find it interesting to build a closer relationship. The universities are mainly potential partners when it comes to projects focusing on process innovation or step-by-step innovation, for instance reducing emissions from combustion plants through the use of simulations.

It can be argued that the lack of contact to the knowledge institutions is not surprising – or of great importance – considering the fabricated metal industry beings an LMT industry. On the other hand, the demand for increasing knowledge content in the products of the fabricated metal industry implies that such contacts become more and more important for Danish firms in order to remain competitive:

> *"Hopefully, the contact to universities will intensify in the future – it is a necessity to capitalise on the strengths of the Scandinavian welfare state in order to make up for the higher labour costs."*
>
> Engineering Director, medium sized firm

Previous research shows that LMT firms primarily cooperate with local universities (Teixeira et al., 2008), and *a second recommendation* is thus to facilitate collaborations between geographically proximate knowledge institutions and fabricated metal firms. Such cooperation can increase the knowledge content in the products, and it is, furthermore, important that Danish fabricated metal firms make use of the high quality of Danish universities in order to compensate for the advantages enjoyed by firms elsewhere.

Similarly to the lack of importance of cooperation between firms and knowledge institutions, governmental policies appear to have a marginal impact on the firms' competitiveness in the case study area. Many of the firms do not consider the available initiatives relevant to them, and only two out of the 17 firms have used some sort of governmental program within the last couple of years. The limited use of governmental initiatives is supposedly partly due to a lack of knowledge about the available offers, but the content of the initiatives is also likely to carry a large part of the responsibility. In this respect, two points should be emphasised:

The first problem is related to the types of innovation processes. Many programmes require that applicants can make it probable that the resulting innovations will be more or less radical. This is rarely the case for innovations in LMT industries, as the clear majority of innovations are incremental or based on the acquisition of capital goods, as shown in this as well as other research projects (Santamaría et al., 2009; Heidenreich, 2009). Furthermore, it may actually be difficult to describe the objective of the innovation process for firms following the innovation strategies oriented towards the customers or step-by-step innovations. The consequence is that the firms are unable to apply for the programs:

> *"We do not get any help, but it should be said that we have never applied for it. It is hard to describe innovation projects, because the customers are most often not sure how the final product should be – and this information has to be stated in the applications."*
>
> Head of Development, large firm

A second problem is that none of the available programs focus on the innovation processes that take place between seller and customer. The small, easy accessible initiatives offered by the Danish Agency for Science, Technology and Innovation such as 'Knowledge Coupon' and 'Knowledge Pilots' are either targeting innovative cooperation between a firm and a knowledge institution (the first) or innovation internally in a firm (the second).

A third recommendation is, therefore, that the Danish government should adopt a broader view on innovation similar to the one found in the Finnish National Innovation Strategy, including initiatives which give higher priority to incremental innovations and innovations based on the acquisition of capital goods. It is, for instance, suggested in one of the interviews that it would be very helpful if the government introduced new products and markets, as smaller firms do not have the resources to prioritise this in everyday life. It is important to remember that the potential benefits of improving the conditions for LMT firms are very large, considering the great economic importance of LMT industries. Changing the way government views and promotes innovation is therefore expected to yield more benefits than costs.

The fundamental argument, which is promoted in this paper, is that it is possible for Danish LMT industries to be competitive, despite the lack of political attention given to them. There is, however, no guarantee that this will be the case onwards, considering the global competition and the increasing skill-level of the populations in especially Asian countries. Politicians cannot take for granted that e.g. the fabricated metal industry will remain competitive when the governmental support structure is based on the needs of high-tech industries. Nor can it be taken for granted that an adequate supply of labour will be available when it is not a political priority to encourage youth to pursue a career within the metal industry. It is thus a necessity to adopt policies which take the needs of LMT industries into account in order to strengthen the competitiveness of Danish LMT firms. A detailed knowledge of how innovation processes take place in these industries is a precondition for such successful policymaking. Hopefully, this paper has offered a contribution in this respect.

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PAPER VI

Declaration of co-authorship

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This co-authorship declaration applies to the following paper:

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The three authors participated equally in all phases of the process of writing the paper, including formulation of the research question and data analysis. However,

Ronnie F. Hansen has:

- Contributed to formulating the focus, problem and conceptual basis of the paper
- Carried out the data preparation
- Drafted the analysis

Teis Hansen has:

- Contributed to formulating the focus, problem and conceptual basis of the paper
- Contributed to writing the theoretical framework of the paper
- Drafted the conclusion

Lars Winther has:

- Contributed to formulating the focus, problem and conceptual basis of the paper
- Contributed to writing the theoretical framework of the paper

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Human Capital in Low-Tech Manufacturing: the Geography of the Knowledge Economy in Denmark

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Abstract

The focus on human capital in discussions of urban and regional growth continues to exert a major influence on urban and regional policies. It is argued that in the knowledge economy, highly skilled labour is crucial for the development of high-tech industries which are considered fundamental engines of economic growth. However, while human capital has been found to have a positive influence on economic development of high-tech industries, there is a need to analyse the use of human capital over time in low-tech industries.

The paper provides such an examination of low-tech industries, based on an analysis of employment data within manufacturing industries in Denmark in the period 1993-2006. The findings highlight, firstly, that human capital appears to be equally important for economic development in low-tech industries and, secondly, that it is the divide between the large urban regions, especially Copenhagen, and the rest of the country, that plays the primary role in explaining the geography of human capital rather than the localisation of high-tech industries. These findings stress the relevance of a broad conception of the knowledge economy which goes beyond high-tech industries.

Keywords

Human capital, low-tech manufacturing, Denmark, knowledge economy, highly skilled labour, creative class, spatial divides

1. INTRODUCTION

This paper is concerned with human capital in low-tech industries. Currently, human capital is regarded as essential to the development of the high-tech sector in Europe. These are industries that often rely on highly analytical knowledge bases (Asheim, 2007), i.e. scientific knowledge and formal R&D innovation, and they are further considered to be crucial engines of economic growth and competitiveness in the western world (Pisano and Shih, 2009). However, studies also reveal the importance of knowledge, knowledge production and innovation in all sectors of the economy including low- and medium-tech industries and also the importance of knowledge relation between high- and low-tech industries (Bender and Laestadius, 2005; Hansen and Winther, 2011b). Thus, it is interesting to analyse the use of human capital over time in low-tech industries, compared to more R&D-intensive industries, where human capital has been found to have a positive influence on economic development (e.g. Murphy and Siedschlag, 2011). This analysis also allows us to examine the close relationship between human capital and the high-tech sector which has been widely embraced by academics and policy makers.

The backbone of the relationship between human capital and high-tech industries is based on the rise of the knowledge economy that has put an emphasis on knowledge, knowledge production, innovation and the institutional set-up that includes knowledge institutions, such as universities and research institutes (Lundvall and Johnson, 1994; Kahin and Foray, 2006; Asheim et al., 2011). The knowledge economy, i.e. the production, use and distribution of knowledge, is seen as the main driver of the competitiveness of firms, cities, regions and nation states. Thus, the knowledge economy has highlighted the importance of innovation in generating competitive environments. Competitiveness of firms increasingly depends on their ability to innovate by improving their productivity (process innovation, including new forms of organisation), product quality or by producing new products (David and Foray, 2002). According to Amin and Cohendet (2004), a critical aspect of the innovation process is knowledge and the understanding of knowledge production as an interactive, relational learning process that relies on people and their abilities and competences. Thus, the rise of the knowledge economy has in the past decades been associated with an increasing attention to human capital (OECD, 1998), knowledge workers (Reich, 1992) and talents (Florida, 2002) that are seen as major resources for economic growth in the capitalist economy in high cost countries. These groups are considered the main source of knowledge production, learning and innovation in economics (Lucas, 1988; Romer, 1990) as well as in the innovation literature (Pianta, 2005). In urban and regional studies, the importance of human capital and talent, as a key resource for regional competitiveness and firm location, has received much attention recently (Glaeser, 1999; Glaeser and Maré, 2001; Florida, 2002; 2003; Stam et al., 2008; Scott and Mantegna, 2009; Andersen et al., 2010; Storper, 2010).

Since the 1990s, there has been an economic resurgence in many large cities and city regions in Europe and North America, driven by the rise of the knowledge economy. Hence, there is currently a strong focus on the geographies of knowledge production and human capital (Urban Studies, 2006; Scott, 2008; Hansen and Winther, 2010). Urbanisation processes and economies strengthen the urban location of economic activities such as high-tech industries, knowledge intensive business services (KIBS), creative, experience and cultural industries. This has changed the urban and regional geographies dramatically in the past decades and the potentials for cities and regions outside the main growth regions, as knowledgeable people are not evenly distributed in space (Storper and Scott, 2009). Studies of the geography of human capital, talents and the creative class in Denmark, Europe and the US support this basic claim (Florida, 2002; Boschma and Fritsch, 2009; Hansen and Winther, 2010). There is a strong spatial division of highly skilled workers within and between regions biased towards the major urban agglomerations.

Thus, the importance of human capital is evident in high-tech industries and KIBS, but little is known of the development and geography of human capital in low-tech manufacturing industries that are geographically concentrated outside the main growth regions. In this paper we focus on manufacturing, distinguishing between high-, medium-, and low-tech industries. Following Lundvall and Johnson (1994) and Asheim (2007) who argue for a broader understanding of the knowledge economy, the main objective of the paper is to examine the use of human capital over time in low-tech industries and thereby challenge the close relationship between human capital and high-tech industries that is often taken for granted in literature and policy documents (e.g. OECD, 2004b; Balconi et al., 2007; Acs and Megyesi, 2009). Accordingly, the paper examines two interrelated issues. First, we compare the change in human capital levels in high-, medium-, and low-tech industries in Denmark to assess the importance of highly skilled labour in non-research intensive industries. Second, we analyse the locational dynamics of highly skilled labour to grasp the development of geographical differences from 1993 to 2006.

The paper is structured as follows. The theories on human capital are outlined in the second section with a specific focus on the emphasis in the literature on the relation between human capital and high-tech industries. The subsequent section briefly describes how this connection has been adopted by policymakers. The fourth section presents the data and methodology, while the fifth section presents the analysis of the locational dynamics of human capital within different types of manufacturing industries. The final section concludes and discusses the findings.

2. Human capital and growth

The knowledge economy has become visible in many places in the economic landscape, but its most important locations are particular places in the large urban regions that generally offer a high degree of accessibility to diverse and qualified labour as well as proximity to knowledge institutions, markets and global linkages (Scott, 2008). Globalisation processes have transformed the economy in Denmark and Europe through for instance increased price competition from low wage countries, the expansion of new markets and a stronger competition among global and local firms. As a result, many firms in Europe have had an enlarged focus on innovation to remain competitive (Maskell and Malmberg, 1999) and new knowledge and learning are fundamental to innovation and firm competition (Lundvall, 1992; Amin and Cohendet, 2004). Thus, the rise of the knowledge economy, i.e. an economy that is based on the production, distribution and use of know-how, has become a most important constituent in the modern European economy.

Human capital, i.e. the competence and knowledge of people to perform as labour, is seen as a key resource in the economy. In mainstream economics, especially endogenous growth theories have applied human capital as an explanatory factor of long term economic growth (Lucas, 1988; Romer, 1990). In these models, human capital is included in the production function in various ways to explain economic growth. In Romer's (1990) model, growth results from accumulated technology and, thus, knowledge, depending on human capital levels. The theory of Lucas (1988) considers the process of human capital formation as the engine of growth – economic growth is considered a result of human capital growth. In urban and regional studies, two main positions associated with the work of Glaeser and Florida have embraced human capital as an important category in explaining urban and regional growth.

Glaeser's work on human capital remains within the framework of mainstream economics in its analysis of city growth in the US. In these studies, human capital is measured as formal education and the results of the econometric analyses show that human capital levels are associated with urban economic growth and can explain the variation between cities (Glaeser, 1994; Glaeser and Saiz, 2004). A further important conclusion is that cities with high levels of human capital are more likely to further attract highly skilled labour (Berry and Glaeser, 2005). Hence, production, attraction and retention of human capital become crucial for cities to grow. Glaeser has moved on to examine the influence of a variety of factors including amenities, climate and consumption opportunities on cities' human capital levels (Glaeser et al., 2001; Glaeser, 2005; Glaeser and Gottlieb, 2006). A main conclusion of the latter works is that if cities are to remain economically successful they must attract highly skilled workers on a basis of quality of life, higher wages and, if possible, a pleasant climate.

In a similar line of work, Florida (2002; 2003; 2005) considers the creative class an essential prerequisite for regional and urban growth in the knowledge economy. The creative class produces creativity and new knowledge that lead to economic growth, as the creativity (and new knowledge) holds the potential of higher levels of innovation and entrepreneurship (Lee et al., 2004). Hence, Florida argues that it is vital to attract creative class members for cities and regions to sustain long term economic growth. He states that in a time of global competition, regions need to attract and hold on to creative and highly skilled labour to be able to attract and retain capital investments. Inflow of human and creative capital becomes increasingly important for production because of the rather footloose character of creative and human capital. By providing the right atmosphere, regions and cities can attract creative people and, with them, investments and firms. Florida claims that the most attractive cities are those that succeed in building a tolerant and diverse atmosphere. Tolerance is considered the single most important factor for attracting creative class members, as creative people are attracted by tolerant, diverse and open-minded places. Thus, Florida emphasises a strong link between talents, urbanisation economies and urban amenities in producing creative regions and cities that can sustain long term economic growth.

While Florida and Glaeser has brought attention to critical aspects of the relationship between regional growth and human capital, the attention given to amenities has been contested, especially by geographers writing from an evolutionary and institutional perspective (Hansen and Winther, 2011a). Both Peck (2005), Pratt (2008) and Storper and Scott (2009) raise important concerns about the role of amenities in the theories, and the further implications for urban and regional policy. In this paper, we address another issue, namely that the many authors in this field overlook the importance of human capital and the creative class for low-tech manufacturing industries that are concentrated in regions outside the main urban areas (see McGranahan et al. (2011) for an analysis of the effect of talents on growth in rural areas). The importance of human capital has been thoroughly examined for high-tech industries, resulting in the widespread understanding that human capital is particularly important for these industries. Below we question the relationship between human capital and high-tech industries as the main driving force behind urban development.

3. Human capital and the high-tech sector

The relationship between highly skilled labour and development of high-tech industries has been the focus of an important strand of the human capital literature (e.g. Zucker et al., 1998; Murphy and Siedschlag, 2011) and various studies focus on the relationship between highly skilled labour, migration and high-tech entrepreneurship (e.g. Wadhwa et al., 2008; Hart and Acs, 2011). In the work of Florida (2002; 2003), the relation between the creative class and high-tech industries is even more pronounced. Florida (2002) focuses on how new communities characterised by weaker ties and greater diversity promote the development of high-tech industries. High-tech industries have superior growth rates in 'creative-class regions', where the lifestyle and diversity attract the creative class that primarily works in high-tech sectors, financial services and the healthcare sector. Thus, the presence of high-tech industries is both an important part of the conditions for attracting the creative class, and a main effect of having a concentration of creative individuals. Florida does not explain the importance of the creative class for low-tech manufacturing industries, but focuses on industries with high R&D-intensity. He maintains this focus in his work on Europe. Florida and Tinagli (2004) stress how the ability of European countries to maintain and attract talent allows these countries to catch up with the US in terms of technological development and growth in high-tech industries.

The close link between highly skilled labour and high-tech industries has been widely embraced within academia (e.g. Balconi et al., 2007). Analysing the US high-tech sector, Bieri (2010) concludes that the distribution of high-tech activity is becoming more unequal, and the positive influence of creativity on the formation of high-tech firms is significant, also relative to increased university spending on R&D. Frenkel (2012) finds that human, social and creative capital have positive influences on the location of high-tech firms, and draws the conclusion that regional policymakers ought to strengthen these assets to attract high-tech firms. Similarly, Chen and Karwan (2008, p. 255) state that *"It is essential for cities and MNEs to adopt innovative ways to continue to attract and retain high-tech employees from pivotal talent pools."* A clear example of an academic paper arguing for a policy focus on the creative class and high-tech industries is the study of Baltimore by Acs and Megyesi (2009). According to them, attracting the creative class is central to the development of high-tech industries which again promotes the transition from an industrial economy to a knowledge-based economy, thus, allowing city regions such as Baltimore to survive and grow, despite increasing global competition. Looking to high-tech areas such as Silicon Valley, Seattle and Boston Route 128, the policy recommendation of Acs and Megyesi (2009, p. 437) in the case of Baltimore is to *"go for a quick fix by attracting talent"* rather than focusing on the improvement of basic skills and a long-term emphasis on education. Whether such policy advice is well-founded and applicable to especially a city with a strong industrial tradition as Baltimore can be questioned, but it is a fact that the competition for highly skilled labour is a main topic among public policymakers today.

4. Highly skilled labour and public policy

In terms of policymaking, there is a general emphasis on high-tech industries in a European context (Hirsch-Kreinsen, 2005; Hansen, 2010; Hansen and Winther, 2011b). Therefore, it is not surprising that the connection between human capital and high-tech industries has been adopted by decision makers (OECD, 2004b). In addition to the increasing importance of the knowledge economy, the competition for highly skilled labour has also been intensified, due to the declining ability of most western countries to produce a sufficient supply. Considering the rising demand for highly skilled labour in developing countries such as India and China, which today are net contributors to the talent pool, there is little hope that the competition will decrease in the years to come (Papademetriou et al., 2009b). The public sector's role in the highly skilled labour contest has increased, and focus is often on the conditions of high-tech industries. When the German Green Card initiative failed to attract the expected numbers of engineers and IT experts, despite preferential treatment of applicants with a certain education or salary level, it was abolished after just three years in 2003 (Collett and Zuleeg, 2008). Elsewhere, policy measures targeting high-tech sector in a more direct way have been applied. In the case of New Zealand, residence permits are more easily obtained by people holding an offer of skilled employment within a *"future growth area"* being biotech, information and communication technology or creative industries (Immigration New Zealand, 2010, p. 31-1). Similarly, the introduction of *"strategic growth visas"* to investors and persons in *"critical industries"* such as biomedical research has been suggested in the US (Meissner et al., 2006, p. 40), perhaps combined with privileged access to employment in industry clusters (like Silicon Valley), specialised in specific sectors (Papademetriou et al., 2009a). Finally, Chen and Karwan (2008) describe how the Chinese government relaxes regulation under certain conditions, e.g. allowing the creation of churches despite the official atheist policy, when it is considered important for attracting high-tech talent.

As the analysis in this paper focuses on the dynamics of human capital in Denmark, it should be noted that the Danish policies towards attraction of highly skilled labour is not explicitly related to the high-tech sector (Mosneaga and Winther, 2011). The immigration policy contains a so-called 'positive list' of occupations with easy access to the Danish labour market, but it is not particularly oriented towards R&D-intensive industries. For the Capital Region of Denmark, attraction and retention of highly skilled labour and talents is a key priority, as it is seen as crucial for the development of a technology-based economy (The Capital Region of Denmark, 2008). However, at the municipality level, the City of Copenhagen stresses that attraction of highly skilled labour is crucial for various innovation processes, including continuous improvements of products and processes, and not just knowledge creation within *"nano and bio"* (City of Copenhagen, 2007, p. 1). Overall, the emphasis on the importance of highly skilled labour specifically for high-tech industries appears to be less pronounced in Denmark than in other countries.

5. METHOD

The analysis is based on register data from Statistics Denmark. The data contains variables on both employment and formal education for the 275 Danish municipalities (the administrative structure used before 2007) on a 2-digit industry level according to the statistical classification of economic activities in the European Community (NACE), as it is defined by Statistics Denmark (2002). Data is available for the years 1993, 1996, 2002, 2004 and 2006, which cover the most recent period of economic growth, and the rise of the knowledge economy in Denmark, before the global economic downturn in 2008 (Nissen and Winther, 2008). For some analyses, the municipal data is aggregated to county level to describe the larger regional developments.

Table 1. Manufacturing Industries classified according to R&D Intensity – NACE-code in brackets

High-tech	**Medium high-tech**
• Office machinery and computers (30) • Radio, television and communication equipment and apparatus (32) • Medical, precision and optical instruments, watches and clocks (33)	• Chemicals and chemical products (24) • Machinery and equipment not elsewhere classified (29) • Electrical machinery and apparatus not elsewhere classified (31) • Motor vehicles, trailers and semi-trailers (34) • Other transport equipment (35)
Medium low-tech	**Low-tech**
• Coke and refined petroleum products (23) • Rubber and plastic products (25) • Other non-metallic mineral products (26) • Basic metals (27) • Fabricated metal products, except machinery and equipment (28)	• Food products and beverages (15) • Tobacco products (16) • Textiles (17) • Wearing apparel; dressing; fur dyeing (18) • Tanning, dressing of leather; manufacture of luggage (19) • Wood and of products of wood and cork, except furniture articles of straw and plaiting materials (20) • Pulp, paper and paper products (21) • Publishing, printing, reproduction of recorded media (22) • Furniture; manufacturing not elsewhere classified (36) • Recycling (37)

Source: Modified from OECD (2004a)

We differentiate industries according to the OECD's classification of technological intensity based on the ratio of R&D expenditures to the output value of the individual industries (see table 1). Unfortunately, our data is restricted to the 2-digit level, while the OECD taxonomy distributes NACE-groups 24 and 35 among several categories. We have assigned both industries to the medium high-tech category, thus, underestimating employment in the high-tech and medium low-tech categories. This is important to consider in the following analysis, especially regarding the high-tech sector that experienced growth over the period within pharmaceuticals, which is here part of NACE-group 24.

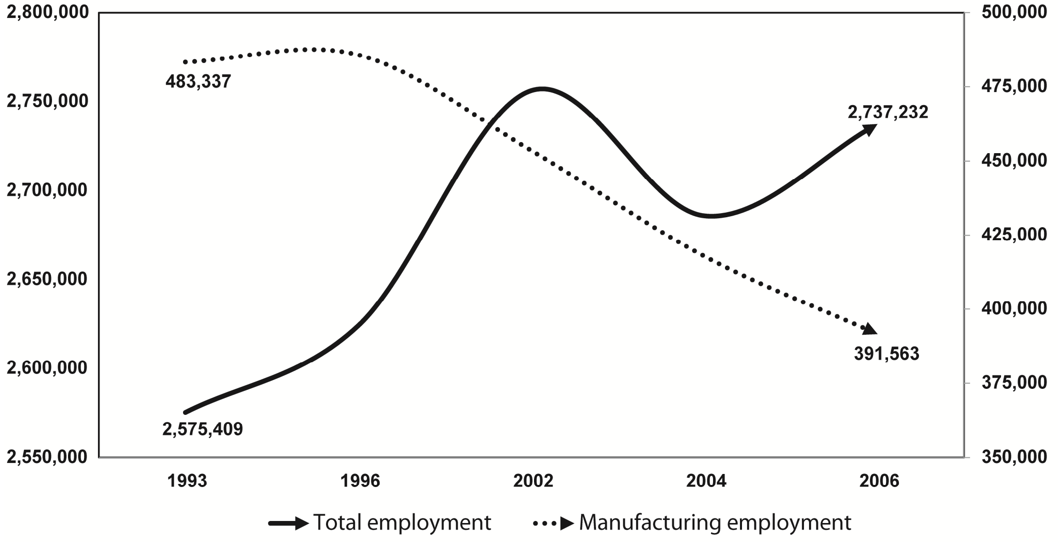
Human capital and talent are contested terms in the academic literature. We follow Glaeser (1994) who uses formal education as a measure of human capital, rather than Florida (2002) who defines talent as people who are employed in creative occupations and are innovative in their everyday work. However, empirical evidence from Denmark and Sweden provided by Hansen (2007) indicates that Glaeser's and Florida's categories are significantly correlated, at least in a Scandinavian context. Analysing data from 2002, the R^2 between the creative class and human capital is 0.852 in Denmark and 0.935 in Sweden. Thus, in our study, human capital, in the form of highly skilled labour, is measured as the share of employees with formal education equalling bachelor's degree, master's degree and PhDs, equivalent to ISCED categories 5A and 6 (UNESCO, 1997).

6. Analysis

6.1. Context – the Danish manufacturing industry

The manufacturing industry in Denmark has experienced a major decline in the number of employees, as in most other Western European countries. The deindustrialisation is a result of increased price competition and outsourcing of production to low wage countries, and the general trend towards a more service and knowledge based economy. Figure 1 shows that Denmark lost more than 90,000 jobs within manufacturing in the period examined. In the same period, total employment rose by more than 160,000. This growth is mainly driven by various producer and business services, the public sector, and creative and experience industries (Hansen and Winther, 2007).

Figure 1. Employment change in Denmark, 1993-2006

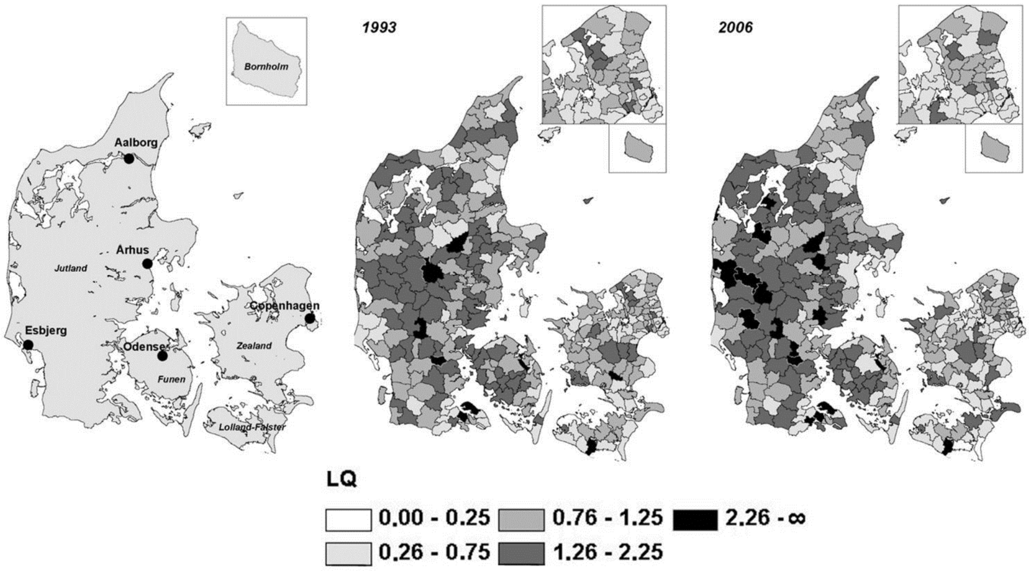


Source: Statistics Denmark and own calculations

However, the manufacturing jobs and the deindustrialisation processes are not evenly spread geographically. Figure 2 shows the location quotient (LQ)[1] of manufacturing jobs in Denmark in 1993 and 2006, respectively. It is clear from these figures that there is a concentration of manufacturing jobs in the western part of Denmark, specifically in the middle and western parts of Jutland, but also in large parts of Funen and in some parts of Zealand. Thus, there is a clear rural/urban divide in the location of manufacturing employment with the jobs being predominantly located in the rural parts of Denmark, i.e. outside the main city regions and urban growth areas. It is clear that this divide has become more profound between 1993 and 2006. Manufacturing is getting less important in the Greater Copenhagen area as well as in the following four major cities in Denmark; Århus, Odense, Aalborg and Esbjerg.

[1] *LQ = (*a_x*/c)/(*b_x*/d)*, where a_x is local employment in industry *x*, *c* is total local employment, b_x is Danish employment in industry *x*, and *d* is total Danish manufacturing employment. LQ = 1 indicates an average concentration of the industry, LQ < 1 indicates under-representation and LQ > 1 indicates over-representation.

Figure 2. LQ of manufacturing employment



Source: Statistics Denmark and own calculations

To differentiate between the changes in employment according to R&D intensity, table 2 takes 1993 as the point of reference. The table reveals that the job loss is considerably higher in low-tech industries than in the other three categories with the number of jobs in 2006 being only 70 % of that in 1993. Medium high-tech industries have experienced a job loss of only 6 %. This can be ascribe to the fact that medium high-tech industries include pharmaceuticals and wind turbine industries, which both experienced considerable economic growth in the last 15-20 years (Valentin and Jensen, 2002; Garud and Karnøe, 2003).

Table 2. Change in employment and share of manufacturing employment, 1993-2006

	1993	1996	2002	2004	2006
	Change in employment (1993 = index 100)				
Low-tech	100	97	85	79	70
Medium low-tech	100	102	99	91	88
Medium high-tech	100	106	103	96	94
High-tech	100	102	104	91	85
Manufacturing total	100	101	94	86	81
	Share of jobs within manufacturing (%)				
Low-tech	47.1	45.3	42.7	42.8	40.8
Medium low-tech	19.8	20.0	20.9	20.8	21.4
Medium high-tech	27.3	28.8	29.9	30.3	31.6
High-tech	5.8	5.9	6.5	6.2	6.1

Source: Statistics Denmark and own calculations

This development has of course had an effect on the share constituted by each R&D category in the manufacturing labour force. As table 2 shows, low-tech industries still accounts for 40.8 % of manufacturing employment in 2006 despite the massive job loss within these industries. Medium low-tech makes up 21.4 % in 2006, whereas medium high-tech's share is 31.6 %. High-tech industries only increase their share by 0.3 % in the period and account for 6.1% in 2006. Thus, Danish manufacturing employment continues to be primarily within non-R&D intensive industries.

6.2. Human capital levels in manufacturing

There has been a strong growth in the employment of highly skilled labour in Denmark in the past decades with an increase close to 90 % between 1993 and 2006, while total employment only grew close to 6 %. Hence, the share of highly skilled labour has increased markedly and accounts for 8.5 % of total employment in 2006 (Hansen and Winther, 2012). There is a profound uneven geography of highly skilled labour. Highly skilled labour is predominantly located in the city region of Copenhagen and partly in the city of Århus, the second largest city. This urbanisation of highly skilled labour has become even more intense between 1993 and 2006 (Hansen and Winther, 2010).

The growth and urbanisation of highly skilled labour can also be found in manufacturing. Table 3 illustrates the development in the share of highly skilled labour in manufacturing industries. From 1993 to 2006, the share more than doubled from 2.4 % to 5.6 %, and it is important to emphasise that the increase is not just due to highly skilled jobs disappearing at a slower rate than low skilled jobs. In fact, the number of highly skilled workers in absolute figures rose by 88 % from roughly 10,800 in 1993 to roughly 20,300 in 2006, which is a growth rate comparable to the increase of highly skilled labour in the economy as a whole.

Table 3. Growth in the share of highly skilled labour, 1993-2006 (1993 = index 100) – percentages in brackets

	1993	1996	2002	2004	2006
Low-tech	100 *(1.7)*	130 *(2.3)*	194 *(3.4)*	214 *(3.7)*	258 *(4.5)*
Medium low-tech	100 *(1.3)*	121 *(1.5)*	150 *(1.9)*	180 *(2.3)*	196 *(2.5)*
Medium high-tech	100 *(3.5)*	120 *(4.2)*	174 *(6.1)*	212 *(7.4)*	239 *(8.4)*
High-tech	100 *(5.9)*	119 *(7.0)*	127 *(7.4)*	151 *(8.9)*	186 *(11.0)*
Manufacturing total	100 *(2.4)*	125 *(3.0)*	174 *(4.1)*	204 *(4.9)*	238 *(5.6)*

Source: Statistics Denmark and own calculations

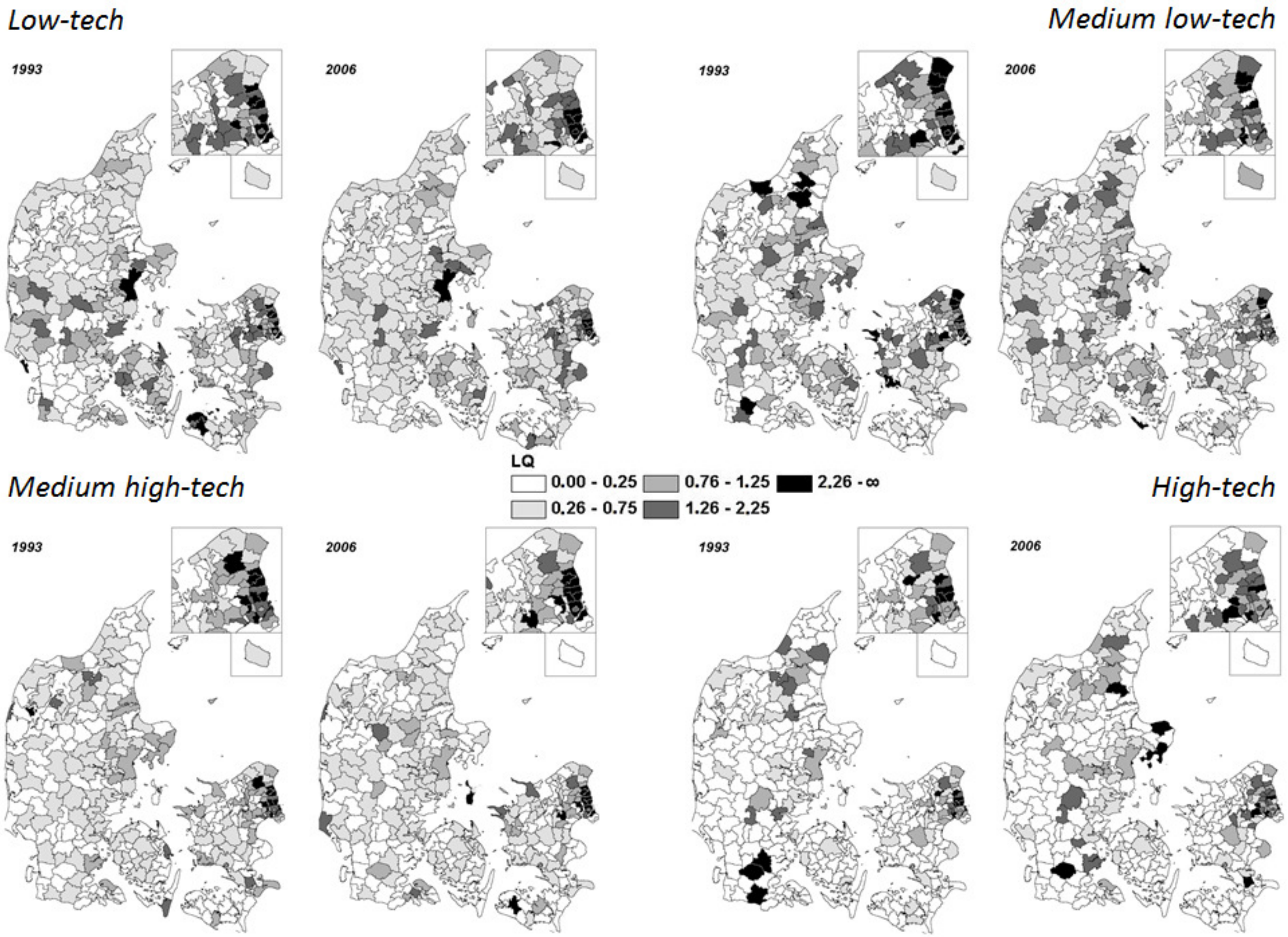
A key issue is whether this increase in the share of highly skilled labour is confined to research intensive industries or a characteristic of manufacturing industries in general. Table 3 shows that the share of highly skilled labour is markedly higher in medium high- and high-tech compared to low- and medium low-tech industries during the entire time period, reaching respectively 8.4 % and 11.0 % in 2006. It is also evident that the share of highly skilled labour is consistently higher in low-tech industries than in medium low-tech industries. This is in itself an interesting finding, which highlights the inadequacy of determining technological intensity solely on levels of R&D investments. An explanation to the difference between the two types of industries might be that while medium low-tech industries gain their innovative capacity through the employment of craft workers with vocational education, the reliance on workers with only primary education in the low-tech industries necessitates the employment of some highly skilled to lead the innovation processes in the firms. In fact, table 3 also shows that the growth in the share of highly skilled labour is highest in the low-tech industries – more than 2.5 times higher in 2006 compared to 1993. Paired sample t-tests, reported in appendix A, show that the growth in the low-tech industries' use of highly skilled labour is significantly higher than the three other types of industries. Further, no significant differences are found between the medium low-, medium high- and high-tech industries.

Summing up, this clearly indicates that the employment of highly skilled labour in manufacturing is not limited to the R&D intensive high-tech and medium high-tech industries. While the share of highly skilled labour in the low-tech industries is still below the average of manufacturing as a whole, the gap to the high-tech industries is decreasing over time.

6.3. The geography of human capital in manufacturing

The previous section showed an increasing share of highly skilled labour in manufacturing industries during the long term period of growth in Denmark. However, our study also shows major geographical differences in the share of highly skilled labour, both at local and regional levels. Figure 3 shows the LQ of highly skilled labour within manufacturing in Danish municipalities in 1993 and 2006 according to R&D intensity. At a general level, the four maps show that the LQ of highly skilled labour is below average in the majority of municipalities in Jutland, Funen and Lolland-Falster. Few municipalities have average or above average LQs. The high LQs are in general found in the Copenhagen metropolitan area and particularly in the municipalities along the Øresund coast to the north of the capital. It is noteworthy that Århus municipality, home to the second most populous city in Denmark, only has a high LQ within low-tech manufacturing and that the third largest city, Odense, shows very low LQs in all four categories. Consequently, the Greater Copenhagen area stands out among the large urban areas in Denmark as the only region with a considerable concentration of highly skilled labour within all types of manufacturing industries. In fact, besides from Århus and rural municipalities with less than 20 talent workers within manufacturing, all municipalities with an LQ of 2.25 or above in at least one of the four R&D categories are pre-

Figure 3. LQ of highly skilled labour according to manufacturing R&D intensity



Source: Statistics Denmark and own calculations

dominantly urban municipalities located in the Greater Copenhagen area (Hansen et al., 2012).

There are, however, some differences between the four R&D categories with regard to how concentrated highly skilled labour is. Highly skilled labour in low-tech manufacturing is exceedingly concentrated in the Greater Copenhagen area and the concentration intensifies between 1993 and 2006. This is also the case for medium high-tech manufacturing. Within medium low-tech and high-tech industries, highly skilled labour is also concentrated in the Copenhagen area, but the concentration does not seem to be intensifying to the same extent.

It is worth stressing that growth in highly skilled labour is closely correlated to overall employment growth – both in terms of manufacturing and total employment (see table 4). While this is in itself not surprising, it should be noted that the correlation coefficient between employment and highly skilled labour growth in manufacturing (0.715) is considerably higher than the corresponding coefficient for the economy as a whole (0.603). Thus, although the question of causality still remains, the presence of highly skilled labour and overall growth appear to be particularly strongly related within the manufacturing industries.

Table 4. Correlation coefficients, municipality scale (n = 270)

	Mean	S.D.	1	2	3
1. Total employment growth, 93-06	4.5	12.2			
2. Manufacturing employment growth, 93-06	-10.6	36.3	0.525		
3. Total highly skilled labour growth, 93-06	70.8	53.7	0.603	0.514	
4. Manufacturing highly skilled labour growth, 93-06	174.8	448.6	0.402	0.715	0.640

All correlations significant at p < 0.001

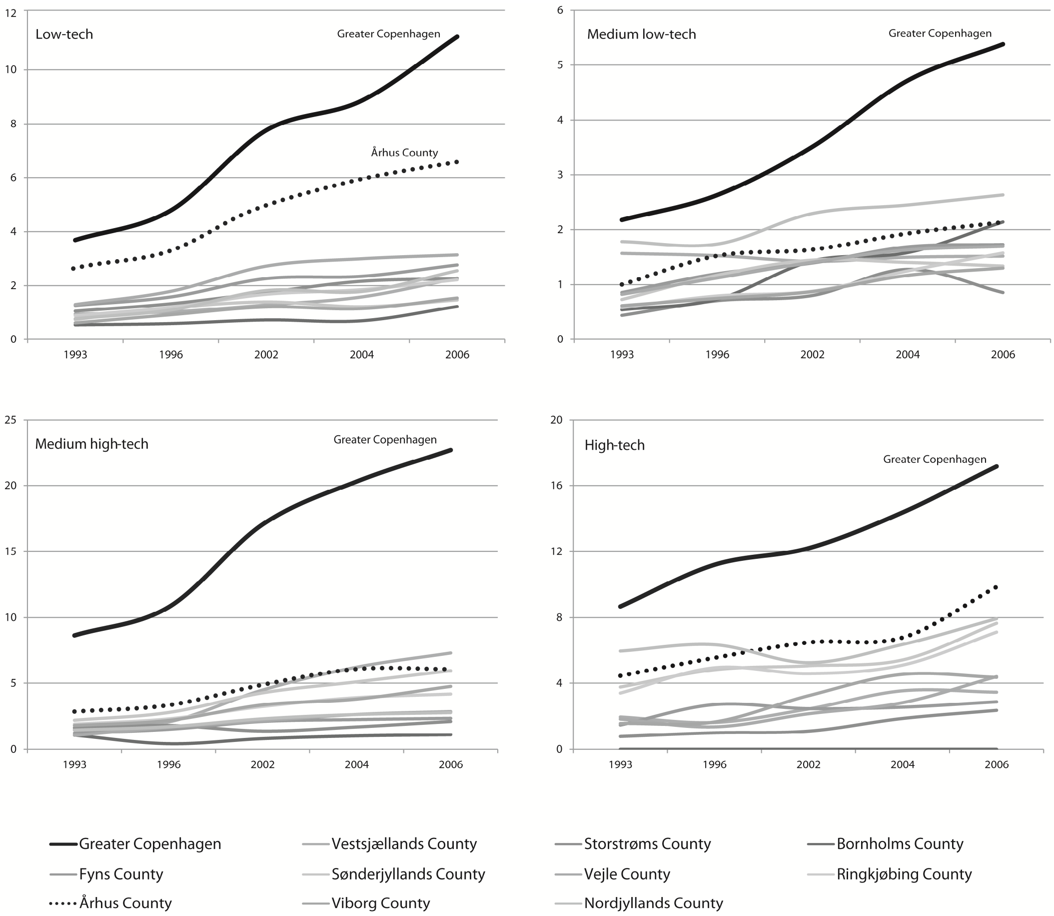
Source: Statistics Denmark and own calculations

To sum up, the maps in figure 3 show, to a large extent, an inverted image of the one presented in figure 2. Even though manufacturing employment is increasingly concentrated in the rural parts of Jutland, employment of highly skilled labour in both low-tech and high-tech industries remains very much an urban phenomenon, concentrated in and around Copenhagen.

The analysis of municipalities points towards an increasing spatial divide between the large urban regions and the rest of the country – especially the industrialised rural regions – concerning employment of highly skilled labour. Still, figure 3 shows that some municipalities in rural regions exhibit high LQs of talent. However, this is primarily explained by the fact that LQ only acts as a measure of concentration, and a limited number of highly skilled workers in a small workforce can therefore result in a high LQ. If municipalities are aggregated to county level, the urban/rural divide becomes even clearer.

Figure 4 provides an overview of the share of highly skilled labour within manufacturing in Danish counties from 1993 to 2006. The tendency towards an increasing share of highly skilled labour in both low- and high-tech industries is clearly visible, and this development is taking place in all counties. There are, however, significant differences in the magnitude of the increase between the counties. At the one end of the scale, the mainly rural county of Bornholm with the smallest manufacturing workforce of all counties has experienced stagnation or very little growth in the share of highly skilled labour. On the contrary, Greater Copenhagen exhibits the highest share of highly skilled labour throughout the time period examined and also shows much higher growth rates in all levels of technology, compared to the other counties. The only other county managing to stand out in terms of growth in the share of highly skilled labour is Århus, and it only does so in low-tech industries. Thus, the analysis at the county level confirms the picture from the analysis at the municipality scale: there is a clear urban/rural divide in the localisation of highly skilled labour within all types of manufacturing industries favouring municipalities in and around Copenhagen, and this divide has deepened over time.

Figure 4. Share of highly skilled labour (%) according to manufacturing R&D intensity, 1993-2006



Source: Statistics Denmark and own calculations

7. CONCLUSION

An essential feature associated with the rise of the knowledge economy has been the increasing focus on the importance of human capital and talent as preconditions for economic growth. Furthermore, in light of the escalating economic globalisation, policymakers and academics also emphasise the crucial character of the high-tech sector, which is thought to be more resistant to global price competition. These two arguments come together in the idea that human capital is particularly important for the economic development of high-tech industries.

The purpose of this paper has been to examine empirically the validity of this argument by analysing the use of human capital over time in low-tech industries. Analysing the changing share of highly skilled labour in Danish manufacturing industries over the period 1993 to 2006 provides little evidence of a particularly close relationship between human capital and high-tech industries. The analysis shows that, while there is a net-increase in the number of highly skilled workers within all types of manufacturing industries, the share of highly skilled labour is growing the most in low-tech industries. In fact, the share of highly skilled labour is now considerably higher in low-tech industries than in the more R&D intensive medium low-tech industries. Thus, human capital appears to be of crucial importance in low-tech industries as well.

Turning to the geographical analysis, the results show a paradoxical development: whereas manufacturing employment is increasingly located in the rural parts of Denmark, the highly skilled labour within manufacturing is predominantly concentrated in the urban regions. Moreover, the data reveals that these geographical differences are intensifying over time. The share of highly skilled labour in the Copenhagen metropolitan area increases significantly throughout the period, especially within the less R&D intensive industries.

These conclusions stress that human capital appears to be equally important for economic development in low-tech industries. Further, the results indicate that the urban/rural divide plays the primary role in explaining the geography of human capital, rather than the localisation of high-tech industries. Hence, it seems that urbanisation economies are strongly underpinning the knowledge economy. These findings have important policy implications. Firstly, while other studies have stressed the significant economic importance of non-R&D intensive industries in developed countries (Kaloudis et al., 2005; Hansen and Winther, 2011b), this study further emphasises that low-tech industries are not merely waiting to be outcompeted by firms from low-cost countries. Rather, they are restructuring and significantly increasing the proportion of highly skilled labour to improve their competitiveness and ability to innovate. It therefore seems misguided to target policies aimed at attraction and retention of highly skilled labour specifically towards high-tech industries.

Secondly, the conclusions raise questions concerning regional policy. It is difficult to imagine a reversal or even a pause in the trend towards a deepening divide in the skill levels of employees in urban and rural locations. Thus, a major challenge for policymakers is to ensure a continuing viability of the manufacturing activity in peripheral locations, taking into consideration the relative decline in educational attainment in comparison with urban regions. The importance of this challenge is underlined by the increasing economic significance of manufacturing in these areas. While the answer may partly lie in the strengthening of inter- and intra-firm linkages to partners with a large share of highly skilled labour (often in urban locations), this topic constitutes an important avenue for future research.

Appendix A

Table A1. Paired sample t-tests for the growth in the share of highly skilled labour, 1993-2006, municipality level

	t	df	P	Mean (1)	Mean (2)
(1) Low-tech – (2) Medium low-tech	3.79	138	0.000	1.77	0.89
(1) Low-tech – (2) Medium high-tech	2.38	157	0.019	1.90	1.28
(1) Low-tech – (2) High-tech	2.07	72	0.042	2.17	1.33
(1) Medium low-tech – (2) Medium high-tech	-1.33	124	0.185	0.93	1.32
(1) Medium low-tech – (2) High-tech	-0.37	60	0.713	1.27	1.42
(1) Medium high-tech – (2) High-tech	0.51	66	0.611	1.45	1.28

Mean values vary, as observations are only included if growth rates can be calculated for both types of industries in the pair

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