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THE ROLE OF UNIVERSITY-INDUSTRY INTERACTION IN REGIONAL INDUSTRIAL DEVELOPMENT

RESEARCH COLLABORATIONS AND GRADUATE HUMAN CAPITAL AS COMPLEMENTARY UNIVERSITY-INDUSTRY KNOWLEDGE TRANSFER CHANNELS

BY
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The role of university-industry interaction in regional industrial development

Research collaborations and graduate human capital as complementary university-industry knowledge transfer channels

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Publications

- Evers, G., 2019. The impact of the establishment of a university in a peripheral region on the local labour market for graduates. Regional Studies Regional Science. 6, 319–330. doi: 10.1080/21681376.2019.1584051
- Germain-Alamartine, E., Ahoba-Sam, R., Saman-Moghadam, S., & Evers, G. (forthcoming). Doctoral Graduates' Transition to Industry: Networks as a Mechanism? Cases from Norway, Sweden and the UK. Studies in Higher Education.
- Guerrero, D. F., & Evers, G. (forthcoming). Co-creation of Localised Capabilities between Universities and Nascent Industries: The Case of Aalborg University and the North Denmark Region. Chapter in book on The Role of Universities in Regional Development and Innovation.

Abstract

The relevance of the university as centuries-old institution has been renewed with the rise of the knowledge-based economy. As research and educational institutions, universities are in a key position to help other actors thrive in an economy in which knowledge has become the main source of competitive advantage. Through the development of their so-called 'third mission', universities can have an impact on society by supplying both public and private actors with knowledge and requisite human capital.

While the internationalisation of academic research and university education has transformed universities into players in global networks, universities still have an undeniable, strong regional character. The knowledge transfer channels between universities and industry tend to be geographically bound owing to the inherent 'stickiness' of knowledge and the immobility of its carriers. The literature shows that both codifiable knowledge interactions—such as patents and publications—as interactions that require physical interaction, tend to benefit from geographical proximity.

Many studies consider graduate human capital and research collaboration to be highly important channels for realising university–industry knowledge transfer. This thesis set out to expand the understanding of how these two university–industry knowledge transfer channels contribute to regional industrial development by answering the following question:

> **What is the role of university–industry research collaborations and graduate production for the impact of universities on regional industrial development?**

The insights are based on analyses of Danish micro-level data, Community Innovation Survey data, interview data, and other data using a variety of empirical techniques. The results highlight the importance of the specific characteristics of regional contexts in relation to the impact of universities on regional industrial development. While universities can play a role in the economic revival of their regions, the extent to which this happens depends on the extent to which the university is related to the industrial specialisation that is prevalent in the region of its location. Failing to achieve this relatedness is likely to reduce the potential contribution of universities to regional industrial development. This thesis argues in favour of a comprehensive approach in which research collaborations and graduate human capital are treated as two interdependent channels. Further, it emphasizes that university–industry knowledge transfer is, in numerous cases, not an automatic process and, therefore, can benefit from deliberate action by both private and public actors to overcome these hurdles.

Finally, it must be noted that miracles regarding regional industrial development must not be expected from university–industry interaction. Universities are, first and foremost, research and educational institutions. However, the increased call for the development of a third mission does not necessarily conflict with this, as this thesis emphasizes that the university missions are not an equal sum game; the third mission activities of universities, like research collaborations, can contribute to the teaching mission by increasing the employment opportunities for graduates and potentially benefit from the university-industry co-evolutionary dynamics that these activities fuel. In this manner, the potential of universities to contribute to regional industrial development can be unlocked.

Resumé

Relevansen af den århundrede gamle institution: universitetet er blevet fornyet med fremvæksten af den videnbaserede økonomi. Som forsknings- og uddannelsesinstitution er universiteter i en vital position for at hjælpe andre aktører med at vokse i en økonomi, hvor viden er blevet den vigtigste kilde til konkurrencefordele. Gennem udviklingen af deres såkaldte 'tredje missions aktiviteter' kan universiteter have en indflydelse på samfundet ved at forsyne både offentlige og private aktører med viden og den nødvendige humane kapital.

Mens internationaliseringen af akademisk forskning og universitetsuddannelse har gjort universiteter til aktører i globale netværk, har universiteter stadig en ubestridelig stærk regional karakter. Ser man på videnoverførsel mellem universiteter og virksomheder er der en tendens til at være en stærk geografisk bias på grund af den iboende 'klæbrighed' af viden og lav geografisk mobilitet af bærerne af denne. Både kodificerbare vidensinteraktioner - såsom patenter og publikationer - samt ikke-kodificerbare vidensinteraktioner, der kræver fysisk interaktion, har en tendens til at drage fordel af den geografiske nærhed.

Mange studier betragter kandidatuddannet humane kapital og forskningssamarbejde som meget vigtige kanaler til realisering af videnoverførsel mellem universiteter og virksomheder. Denne afhandling har til formål at udvide forståelsen af, hvordan disse to videnoverførselskanaler mellem universiteter og virksomheder bidrager til regional industriel udvikling ved at besvare følgende spørgsmål:

> **Hvilken rolle spiller universitets-industri forskningssamarbejde og kandidatproduktion for universiteternes indvirkning på regional industriel udvikling?**

Afhandligen er baseret på analyser af danske registerbaserede data på mikroniveau, Community Innovation Survey-data, interviewdata og andre data ved hjælp af en række forskellige empiriske metoder. Resultaterne viser betydningen af de specifikke karakteristika i regionale sammenhænge i relation til universiteternes indvirkning på regional industriel udvikling. Mens universiteterne kan spille en rolle i den økonomiske genoplivning af regioner, afhænger omfanget af dette, i hvilket omfang universitetet er relateret til den industrielle specialisering, der er fremherskende i området. Hvis man ikke opnår denne tilknytning, reduceres sandsynligvis universiteters potentielle bidrag til den regionale industrielle udvikling. Denne afhandling argumenterer for en omfattende tilgang, hvor forskningssamarbejde og human kapital behandles som to indbyrdes afhængige kanaler. Det understreger endvidere, at videnoverførsel mellem universitet og industri i mange tilfælde ikke er en automatisk proces og derfor kan drage fordel af bevidst handling fra både private og offentlige aktører for at overvinde disse forhindringer.

Endelig skal det bemærkes, at mirakler med hensyn til regional industriel udvikling ikke må forventes gennem et samspil mellem universitet og industri. Universiteter er først og fremmest forsknings- og uddannelsesinstitutioner. Den øgede opfordring til udvikling af tredje missions aktiviteter strider imidlertid ikke nødvendigvis med dette, da denne tese understreger, at universitetsmissionerne ikke er et nul sum-spil; universiteters tredje missionsaktiviteter, ligesom forskningssamarbejde, kan bidrage til undervisningsmissionen ved at øge beskæftigelsesmulighederne for kandidater og potentielt drage fordel af den universitetsindustrielle co-evolutionsdynamik, som disse aktiviteter skaber. På denne måde kan der åbnes op for universitetets potentiale til at bidrage til regionale industrielle udvikling.

Samenvatting

De relevantie van de universiteit als eeuwenoude institutie is vernieuwd met de opkomst van de kenniseconomie. Als onderzoeks- en onderwijsinstellingen bevinden universiteiten zich in een sleutelpositie om andere actoren te helpen gedijen in een economie waarin kennis de belangrijkste bron van concurrentievoordeel is geworden. Door de ontwikkeling van hun zogenaamde 'derde missie activiteiten' kunnen universiteiten een impact hebben op de samenleving door zowel publieke als private actoren te voorzien van kennis en het benodigde menselijk kapitaal.

Terwijl de internationalisering van academisch onderzoek en universitair onderwijs universiteiten heeft veranderd in spelers in mondiale netwerken, hebben universiteiten nog steeds een onmiskenbaar, sterk regionaal karakter. Wanneer er gekeken wordt naar de kanalen voor kennisoverdracht tussen universiteiten en het bedrijfsleven, is er vaak een sterke geografische patroon zichtbaar vanwege de inherente 'plakkerigheid' van kennis en haar dragers. Zowel codificeerbare kennisinteracties—zoals patenten en publicaties—als interacties die fysieke interactie vereisen hebben baat bij geografische nabijheid.

Veel studies beschouwen universitair geschoold menselijk kapitaal en onderzoekssamenwerking als zeer belangrijke kanalen voor het realiseren van kennisoverdracht tussen universiteit en het bedrijfsleven. Dit proefschrift heeft tot doel de kennis te vergroten over hoe deze twee kanalen voor kennisoverdracht tussen universiteiten en het bedrijfsleven bijdragen aan de regionale industriële ontwikkeling. Hierbij staat de volgende vraag centraal:

> **Wat is de rol van onderzoekssamenwerking tussen universiteiten en industrie en het leveren van universitair geschoold menselijk kapitaal voor de impact van universiteiten op regionale industriële ontwikkeling?**

De inzichten zijn gebaseerd op analyses van Deense microniveau-data, Community Innovation Survey-data, interviewdata en andere data met behulp van verschillende empirische technieken. De resultaten benadrukken het belang van de specifieke kenmerken van regionale contexten in relatie tot de impact van universiteiten op regionale industriële ontwikkeling. Hoewel universiteiten een rol kunnen spelen in de economische heropleving van hun regio's, hangt de mate waarin dit gebeurt af van de mate waarin de desbetreffende universiteit gerelateerd is aan de industriële specialisatie die heerst in de regio van haar locatie. Als deze verwantschap niet wordt bereikt, zal de potentiële bijdrage van universiteiten aan de regionale industriële ontwikkeling waarschijnlijk afnemen. Dit proefschrift pleit voor een alomvattende aanpak waarin onderzoekssamenwerkingen en universitair geschoold menselijk kapitaal worden behandeld als twee onderling afhankelijke kanalen. Verder benadrukt het dat kennisoverdracht tussen universiteit en het bedrijfsleven in veel gevallen geen automatisch proces is en daarom kan profiteren van gerichte acties van zowel private als publieke actoren om deze hindernissen te overwinnen.

Ten slotte moet worden opgemerkt dat er met betrekking tot regionale industriële ontwikkeling geen wonderen mogen worden verwacht van de interactie tussen universiteit en het bedrijfsleven. Universiteiten zijn in de eerste plaats onderzoeks- en onderwijsinstellingen. De toegenomen roep om de ontwikkeling van een derde missie is hier echter niet noodzakelijkerwijs in strijd mee, aangezien dit proefschrift benadrukt dat de derde missieactiviteiten van universiteiten, zoals onderzoekssamenwerkingen, kunnen bijdragen aan de onderwijsmissie door de werkgelegenheid voor afgestudeerden te vergroten en mogelijk te profiteren van de co-evolutionaire dynamiek tussen universiteiten en het bedrijfsleven die deze activiteiten voeden. Op deze manier kan het potentieel van universiteiten om bij te dragen aan regionale industriële ontwikkeling worden ontsloten.

Contents

Preface

On Tuesday, 28 February 2017, at 10:00 am, I first set foot on Danish soil. This was a deliberate step intended to develop myself as a researcher and expand my horizons. In the little over three years that have passed since then, I have been working on a PhD project aimed at understanding the role of university–industry interaction in regional industrial development. This thesis contributes to a longstanding discussion on how universities can realise societal impacts. Without spending too much time here discussing the relevance of this work, I quote Franklin Roosevelt's 1940 address to the University of Pennsylvania:

> This is not a time for any man to withdraw into some ivory tower and proclaim the right to hold himself aloof from the problems and the agonies of his society. (Roosevelt, 1940)

While current circumstances are rather different, the coronavirus pandemic has reminded society of the importance of the scientific community for addressing global challenges. In the coming decades, various other global challenges must be overcome, not the least climate change, in which universities have the potential to provide a crucial contribution. Understanding how this can be done is of key importance. The following pages contain my efforts to contribute to the development of this understanding. Before you continue to the results, I would like to briefly reflect on how this thesis came into being.

This PhD project was part of the RUNIN project (the Role of Universities in Regional Development and Innovation), which was funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie Grant Agreement No. 722295. Within the Innovative Training Network of RUNIN, I was accompanied by 13 other early-stage researchers from all over the globe who were hosted by universities in 7 different European countries. From the outset, we were connected by our related enquiries into the role of universities in regional development and innovation; all our individual projects added a piece to the larger puzzle, thereby improving the understanding of the roles of universities and a variety of other public and private actors fulfil in this context. Together with Eloïse Germain-

Alamartine, Rhoda Ahoba-Sam, and Saeed Moghadam-Saman, I was part of a work package that focused on the role of people and networks in relation to the role of universities in regional development and innovation.

Being part of the Innovative Training Network enabled me to participate in eight RUNIN training weeks, which covered a wide range of academic content, transferable skills, and social activities. In addition, other training weeks and conferences were useful for learning as well as building networks, and also online courses and learning-by-doing greatly contributed to the development of my skills during the PhD programme.

Apart from the inevitable setbacks that are encountered during a PhD programme, I consider this period to be successful in terms of both research and personal development. I enjoyed being part of the international community of people that I came to know in Aalborg and across Europe. Immersion in this community enabled me not only to learn about numerous different cultures and countries but also gain a better perspective on my own background. In addition, being surrounded in the academic context by so much research expertise has been humbling as well as a valuable learning opportunity.

I hope that the insights provided in this thesis will fuel academic and policy discussions and inspire people to take action aimed at incorporating these insights into policy.

Gerwin Evers
Aalborg, April 2020

Acknowledgements

I could not have completed this journey on my own. Although these acknowledgements are not ordered in terms of importance, the person to whom I owe the most gratitude is Christian Richter Østergaard, my supervisor, for his guidance throughout the PhD programme. I enjoyed the non-hierarchical nature of our discussions and his emphasis on getting to the essence of the story.

I would like to express my gratitude to my second supervisor, Rebecca Herron, for hosting me in the autumn of 2017 for a secondment at the University of Lincoln and for showing interest in my research and personal development. I am also grateful for the secondment opportunity provided to me at the University of Stavanger in the autumn of 2018. During these secondments, I enjoyed the opportunities to present my research as well as connect with the local academic community, particularly with other PhD candidates. I also enjoyed the talks and other interactions with Maria Theresa Norn from the think tank DEA in Copenhagen, who was assigned as my RUNIN project mentor. Further, I am grateful to all the other people involved in the RUNIN project who inspired me and made the secondments, training weeks, and project as a whole possible.

From the RUNIN group, I would particularly like to thank my officemate and friend, David Fernández Guerrero. Obtaining a PhD can be challenging, so I appreciated being accompanied by someone who was on the same journey. I learned a lot from our conversations, both in and out of the office. For the same reason, I enjoyed being embedded in the IKE research group. In particular, I would like to thank Ina Drejer and Jeanette Hvarregaard for all their efforts related to my PhD project. In addition, the IKE 'juniors', some of whom may have graduated in the meantime from this stage, were a beneficial community both within and outside the university context.

I would like to thank my fellow board members at the PhD Association of Aalborg University (PAU) for providing a distraction from my PhD research, which was necessary on occasion. Finally, I would like to thank my friends, family, co-authors, reviewers and all the other people who directly or indirectly contributed to or supported the realisation of this thesis.

Thesis Details

Thesis Title: The role of university-industry interaction in regional industrial development
PhD Student: Gerwin Evers
Supervisor: Professor Christian Richter Østergaard, Aalborg University

The main body of this thesis consist of the following papers. It is preceded by a synopsis that functions as an introductory section.

[A] Evers, G. (2019). The impact of the establishment of a university in a peripheral region on the local labour market for graduates. *Regional Studies, Regional Science*, 6(1), 319–330. doi: 10.1080/21681376.2019.1584051

[B] Evers, G. The alignment of universities' teaching mission with the demands of regional industry. *Currently under review*

[C] Guerrero, D. F., & Evers, G. (Forthcoming). Co-creation of Localised Capabilities between Universities and Nascent Industries: The Case of Aalborg University and the North Denmark Region. Chapter in book on *The Role of Universities in Regional Development and Innovation*.

[D] Evers, G. The effect of university-industry collaborations on firm-level human capital. *Working paper*.

[E] Evers, G., & Chappin, M.M.H. Knowledge Sharing in Smart Grid Pilot Projects. *Currently under review*

[F] Germain-Alamartine, E., Ahoba-Sam, R., Saman-Moghadam, S., & Evers, G. (Forthcoming). Doctoral Graduates' Transition to Industry: Networks as a Mechanism? Cases from Norway, Sweden and the UK. Studies in Higher Education.

This thesis has been submitted for assessment in partial fulfilment of the PhD degree. The thesis is based on the included scientific papers listed above. Parts of the papers are used directly or indirectly in the extended summary of the thesis. As part of the assessment, co-author statements have been made available to the assessment committee.

Part I

Synopsis

1 Introduction

The rise of the knowledge-based economy has increased the societal relevance of universities all around the world. As knowledge reservoirs, universities are set to play an important role in an economy in which knowledge has become the main source of competitive advantage (OECD, 2005). In the ongoing debates regarding the role of universities in the knowledge-based economy, some argue that this role manifests particularly strongly at the regional level (Pinheiro et al., 2012).

In order to understand the rise of the university as an important actor in the knowledge-based economy, it is necessary to understand how the development of such an economy affects the potential of universities as societal actors. The knowledge that universities produce is not limited to facts but includes all kinds of relevant information, experiences, and insights (Davenport & Prusak, 1998). Knowledge of products, customers, markets, and technologies is crucial for firms to offer current and future value propositions to their customers. This implies that access and utilisation of knowledge affects firm performance and, in turn, the prospering of regions. Therefore, the skills required to learn and obtain new knowledge have become a major force in explaining why organisations flourish or perish (Lundvall & Johnson, 1994).

1.1 Knowledge generation in the knowledge-based economy

The awareness among firms of the increased importance of knowledge has led to the allocation of more resources to strengthen their knowledge position. Investments in research and development (R&D) staff and facilities are intended to yield knowledge that could, in the (near) future, contribute to improving a firm's competitive position by helping to outsmart competitors (Doraszelski, 2003). In this context, organisations must ensure that the knowledge derived by individual researchers can be disseminated at the organisational level and across organisational boundaries (Kim, 1993; Ulrich et al., 1993). By structuring this process, knowledge management plays an important role in ensuring the efficient use of R&D resources (Darroch, 2005).

In addition to private R&D conducted by companies, a considerable proportion of R&D is performed by higher education institutions, such as universities (OECD, 2019c). Universities usually allocate the majority of their research funds to the more basic research (National Science Foundation, 2014). These investments are deemed less suitable for private investments due to the complexity and uncertainty regarding payoff and the likelihood of generating social returns that cannot be fully incorporated by the firm in question (Nelson, 1959). The presumed social returns stem from the potential of basic research to increase the stock of knowledge, develop new methodologies, and train new researchers in the process (Salter & Martin, 2001). In this pattern, universities push the boundaries of science forward, while firms are better positioned to develop these findings further into marketable innovations (Rosenberg & Nelson, 1994). In this manner, many of the important technologies developed in previous decades have been enabled by university research (Mazzucato, 2011).

The aforementioned outcomes of basic research already indicate large heterogeneity in the different forms of knowledge. Knowledge does not refer only to the tangible outcomes of research activities, such as publications, patents, and the like. In this context, an oft-made distinction is between tacit and codified knowledge (Polanyi, 1966). Codified knowledge can be formally expressed and recorded and, hence, become part of organisational procedures and transmitted via guidelines, manuals, and publications to both members of the organisation and outsiders. Management of codified knowledge has been widely discussed in the literature (Zack, 1999). In contrast, tacit knowledge is held by employees in the form of experiences and skills that guide their behaviour. This type of knowledge is not suited for transmission and management in the same manner as codified knowledge. Although organizations have attempted to develop strategies to codify tacit knowledge, it turned out to be a difficult task (Ancori, 2000), as Polanyi (1966, p. 4) stated, *"We know more than we can tell"*. Even if codification appears possible, contextual information that is difficult to be written down still matters for the interpretation and the use of the knowledge (Ancori, 2000; Zack, 1999). Distributing tacit knowledge requires intensive interaction (Lundvall & Johnson, 1994), and trust is crucial in the inter-organisational dynamics to create a context in which knowledge sharing can take place. Absence of trust may lead the participants in a knowledge sharing interaction to fear opportunistic behaviour or be uncertain regarding the quality of the transmitted knowledge (Easterby-Smith et al., 2008). This implies that inter-personal dynamics have a focal role in the handling of tacit knowledge; even if knowledge might be considered an organisational asset, individuals are the loci of this asset.

1.2 Human capital in the knowledge-based economy

The importance of individuals as key actors in knowledge dynamics is also reflected in the increasing importance of human capital. The OECD (2001, p. 18) defines human capital as *"the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being"*. Thus, individuals are not replaceable homogeneous units but are equipped with knowledge—such as skills and competencies—that offers value to employers that is not easy to replace. Human capital is considered to be one of the key factors determining the productivity of individual employees and, thereby, firm-level productivity (Berman et al., 1998). These returns are not only concentrated in the typical knowledge-intensive occupations—investments in human capital at all different educational or experience levels improves the labour market outcomes of individuals (Becker, 1962; Psacharopoulos, 1985). Having relevant knowledge that is gained through either experience or training enables individuals to develop a better understanding of the kind of changes that are required and, hence, individuals with more human capital are more likely to innovate (Dakhli & De Clercq, 2004; Marvel & Lumpkin, 2007).

The inimitability of human capital is key to the value it offers to firms. While employees can be acquired, the firm-specific knowledge they hold decreases in value when transferred to a different context (Hitt et al., 2001), non-competition agreements are used to inhibit this transfer (Rubin & Shedd, 1981), or adjustment costs need to be made in order to retain the value of this knowledge (Hatch & Dyer, 2004).

This has made that human capital is even deemed to be the most important and largest stock of capital (Becker, 2006). Having a high level of human capital is also likely to generate some Matthew effects by increasing the ability of these employees to absorb new knowledge (Cohen & Levinthal, 1990) and receive further training (Barron et al., 1999). Having this absorptive capacity is crucial for enabling inter-organisational learning and transfer of knowledge (Lane & Lubatkin, 1998) and, in turn, enhancing the innovation capacities and financial performance of firms (Kostopoulos et al., 2011).

Awareness of this advantage has led to widespread adoption of on-the-job and off-the-job training policies to increase the level of human capital and customise it to the firms' needs (Mincer, 1962; Smith, 2002). Human capital development is deemed to be a vital part of the strategy of innovative firms (Baldwin & Johnson, 1995), and investments in employee training are considered to contribute to firm performance (Hansson, 2007). However, concerns have been raised regarding the transferability of skills when employees change employers, which might make that the investing firm may not capture the returns on the investments in training (Greenhalgh & Mavrotas, 1996). The more generic the acquired skills, the easier these skills can be taken to a different employer (Becker, 1962). Hence, this is also one of the rationales for providing public funding for and organising formal education at public primary, secondary, and tertiary education institutions equipping students with more generic knowledge that has due to it more generic character value across firms and, to some extent, industries.

While all levels of education tend to increase the value of individuals to potential employers, in recent years there has been an increased interest in university graduates (OECD, 2016a). The widespread use of the Humboldtian model of university education, which advocates for combining research and teaching in a single institution, presumes that synergies can be realised by doing so (Schimank & Winnes, 2000). The research experience employed in the teaching familiarises students with the recent scientific knowledge in the field, learns them to apply the knowledge, and—critically, often at an abstract level—reflect on this knowledge (Neumann, 1992). This high-level human capital enables individuals to understand and work on complex processes, products, and services. However, university education can be costly, particularly when opportunity costs—like reduced income during the time studied—are considered. Although students could—and maybe should—be intrinsically motivated for their study, and the social prestige of having a university degree might also serve as an incentive (Hollingshead, 1975), ultimately, university education is regarded as an investment that is likely to strengthen their position in the labour market (Abel & Deitz, 2014).

Employers—and not only those from knowledge-intensive sectors—consider having a university degree to be a prerequisite or added value for applicants in the hiring process (Finch et al., 2016). While presumed learned resources, such as scientific knowledge and an ability to handle new knowledge in these graduates might be what the recruiters are looking for (Finch et al., 2016), the selection of, admission into, and completion of a university degree is also likely to signal innate intellectual ability and perseverance (Arrow, 1973; Schmidt & Hunter, 1998). By assigning importance to graduate human capital, whether it is for graduates' education or use it as a filter for detecting the innate capabilities, indicates that employers presume that it contributes to the productivity—and thereby performance—of the firm (Crook et al., 2011). Although it is likely that firms will need to allocate substantial investments for freshly hired graduates in order to adapt their human capital to the specificities of the workplace, their enthusiasm and critical thinking may bring new ideas and knowledge into the firm (Salter & Martin, 2001). This is why firms have an increasing propensity to focus their recruiting efforts on university graduates, as the latter possess human capital that is relevant to the knowledge-based economy (Berman et al., 1998).

1.3 Reconsidering the role of the university

The importance of university-level human capital to employers and economic success has fuelled all across the world a huge growth in the number of graduates throughout the last few decades of the twentieth century. During this time, the number of universities doubled, existing universities grew in size, and the number of students grew exponentially, thereby making university education a good of the masses (Schofer & Meyer, 2005). However, the rapidly growing student numbers, particularly from the 1980s onwards, put increasing pressure on the public funding of higher education at a time when many developed economies were experiencing some economic slowdown (Zomer & Benneworth, 2011). In addition, concerns were rising with regard to the societal returns of scientific breakthroughs that were made possible by the public funding allocated to universities (Stevens, 2004). This fuelled a discussion regarding how universities could contribute to the society they were part of. Although universities were considered key institutions for the progress of the knowledge-based economy, numerous critics claimed that they were like 'ivory towers'—cut off from the developments in their direct environment (Shapin, 2012). In other words, universities were only existing *"in"* rather than part *"of"* their environment (Bender, 1998; Chatterton, 2000, p. 166)

In response to these developments, universities were encouraged and pressurised to develop, in addition to their traditional missions of teaching and research, a third mission of external engagement with the communities in which they were located (Perkin, 2007). This third mission—which can also be referred to as valorisation, transfer, the third stream, or the entrepreneurial university—was deemed necessary with the development of the understanding that university knowledge does not merely flow into and become absorbed in the form of codified knowledge by external actors but rather that its transfer requires interactions to take place (Laredo, 2007). The development of this mission reconceptualised universities from ivory towers into entrepreneurial actors driving change (Etzkowitz & Leydesdorff, 2000). The locus of the prime impact of the third mission was argued to be regional, as will be discussed in the next paragraph (Trippl et al., 2015).

1.4 A regionally oriented mission

The understanding of the third mission being regional contrasts with the notion of universities as actors in globalised networks in which they co-generate knowledge, primarily with other academic actors (Power & Malmberg, 2008). Over the last few decades, academia has become increasingly characterised as a global community that hosts an international workforce and student population (Adnett, 2010; Walker, 2015). Following the same trend, English has become increasingly important as the lingua franca for both teaching and publishing research (Wächter & Maiworm, 2014). Academic networks are increasingly being characterised as having an international scope due to participation in international meeting platforms, such as conferences and workshops (Liberman & Wolf, 1997). This has also enabled the rise of international co-publications, which also tend to be more cited than solo papers or domestic co-publications (Glänzel et al., 1999; Katz & Hicks, 1997).

However, there have been a wide range of studies addressing the various regional impacts of universities. The first type of regional impact can be considered to consist of the direct impacts. Universities generate employment by creating jobs for both academic, administrative, and support staff, while also employing a variety of people for other services, such as cleaning, catering, and maintenance (Siegfried et al., 2007). In addition, the investment of universities in real estate can play an important role in revitalising urban areas (Wiewel & Perry, 2015). In turn, the employment generated by the university and the inflow of both staff and students from outside the region also generates widespread demand for a wide variety of businesses (Garrido-Yserte et al., 2010). This might spark investments in local public transport, while the international workforce, students, and networks of universities also create demand for international airport and train connections. Further, the presence of a well-educated workforce creates a demand for culture; moreover, universities play an important role by providing resources, expertise and facilities to a wide range of cultural organisations, such as orchestras, museums, and libraries (Chatterton, 2000). Moreover, universities contribute directly to social and cultural life through sport teams, facilities, and a variety of other activities, thereby increasing the attractiveness of the their locality (Laredo, 2007). Universities can also play a role in informing and influencing policy processes through its knowledge base (Breznitz & Feldman, 2012) and enhance the public understanding of science (Laredo, 2007). Although all these direct impacts definitely constitute clear regional societal returns on the investments in the university, these or similar effects could most likely also be realised with an alternative allocation of these resources for the public benefit. Therefore, it is important to consider the more indirect impacts of universities. These impacts must be found in the domain of regional industrial development, in which university knowledge could make a difference in the development of regional industrial activities (Charles, 2006).

1.5 Regional economic impact through university knowledge spillovers

As discussed earlier, knowledge is increasingly important for sustaining competitive positions in the knowledge-based economy (OECD, 2005); moreover, as Chesbrough (2003, p. xxvi) noted, *"not all the smart people work for us, we* *need to work with smart people inside and outside our company"*, thereby emphasizing the necessity for firms to not only rely on internal R&D sources. The increasing complexity and variability of technologies and markets demand companies to pursue a more open innovation strategy (Nooteboom, 1999) in which relying to a certain extent on external sources can foster firms' innovation performance (Laursen & Salter, 2006). While firms can turn to competitors or suppliers for this purpose, none of these is likely to match the knowledge position and independence of universities, thereby placing universities in a unique and crucial position within regional innovation systems (Charles, 2006).

Further, while the mobility of products and services has increased with the help of globalised logistic and IT networks enabling them to compete in global markets, the knowledge involved in their production tends to be rather sticky and geographically bounded because of place-specific experience and tacit knowledge (Asheim & Isaksen, 2002). Learning capabilities, informal institutions, and the configurations of actors and their expertise that facilitate their creation are difficult to move or replicate across space (Lundvall, 1992; Markusen, 1996). Knowledge spillovers also tend to have a rather local dimension (Audretsch & Feldman, 2004), and geographical proximity is increasingly important if knowledge is transferred to different institutional settings (Boschma, 2005). Hereby, knowledge is *"one of the few remaining genuinely localized phenomena in this increasingly 'slippery' global space economy is precisely the 'stickiness' of some forms of knowledge and learning processes"* (Malmberg, 1997, p. 574). Therefore, according to M. E. Porter (1998), competitive advantages in the global economy are increasingly dependent on local resources, like knowledge, that are more difficult to access for competitors outside the region. Hence, regional industrial development, consisting of the growth and survival of firms and thereby industries, depends on firms' access to and ability to utilise the knowledge available in the region, in which universities are envisioned to play a significant role.

However, the knowledge spillovers required to unlock this potential of universities for regional industrial development are not externalities that flow through the air, but the result of deliberate actions (Breschi & Lissoni, 2001). Numerous studies have surveyed academic and industry actors regarding the way in which these spillovers appear at the university–industry interface. Three main approaches are adopted to examine this. First, some studies focus on assessing the frequency with which actors participate in certain knowledge transfer channels. Second, studies investigate the importance of these channels for university–industry knowledge transfer. Third, some studies assess the relative importance of all these channels. Table 1 on page 11 provides an overview of some of the most cited studies on this topic, distinguishing between the main channels for knowledge spillovers and how these are assessed by university and industry actors. The darker the shading, the more importance a study ascribes to a particular channel in comparison to the other channels discussed in that study. In this way the top line shows that Schartinger et al. (2001) found that 32% of respondents participated in contract research and, as evidenced by the black shading, deemed this to be one of the most commonly used channels.

For the purpose of this review, the channels are distinguished into six groups—intellectual property, research services, research output, research collaborations, informal interactions and human capital. Several further classifications and rankings of these channels have been proposed in the literature. Mowery and Ziedonis (2015) distinguish channels based on the nature of the transaction in which the university knowledge is disseminated, ranging from market-mediated channels such as intellectual property and research services to knowledge spillovers derived from collaborations and informal interactions. Perkmann and Walsh (2007) rank the channels based on the extent of relational involvement, with high relational involvement in research collaborations and services, medium for human capital and spin-offs, and low relational involvement for patents and licensing. Link et al. (2007) classify the channels into formal collaborations, such as intellectual property, and the more informal ones such as research collaborations and informal interactions. The following sections briefly discuss the channels, their impact on regional economic development, and the relevance of these channels for this thesis.

1.5.1 Intellectual property

The first group of channels comprises activities in which the university assumes the role of a private actor and employs activities aimed at the direct commercialisation of university knowledge in patents and spin-offs. These activities are intended to generate income for universities and, in so doing, reduce their reliance on public funding. The Bayh-Dole Act in the US aimed to encourage these developments by creating an incentive for academics and universities to become involved in these activities (Stevens, 2004). Not only the US, but other countries also adopted similar policies to facilitate the commercialisation of university knowledge (Mowery & Sampat, 2004). Subsequently, universities witnessed a huge increase in patenting over the last few decades of the twentieth century (Henderson et al., 1998). Applying for a patent requires disclosure of relevant knowledge (Gallini, 2002) and, hence, offers interested industry actors—with a strong geographical bias towards local actors (Jaffe et al., 1993)—insight into the knowledge generated in universities. The subsequent licensing of patents to private actors cannot only enable other actors to exploit the intellectual property but also is set to generate economic returns on the investments made in the development of the knowledge. The licensing of private actors tends to be more geographically con-

Table 1: University–industry knowledge transfer channels discussed in the literature

			Intellectual property			Services		Research Output	Collaborations		Informal interactions			Human capital		
		Channels	Patents	Licensing	Spin-offs	Consulting	Contract research	Publications	Joint research	Research facilities	Meetings	Networks	Teaching collaboration	Training industry	Labour mobility	Graduates
Authors	*Country*	Sample	*Participation (% of respondents that participated in knowledge transfer channel)*													
Schartinger et al.(2001)	Austria	Academics in all disciplines	-	-	14	-	32	-	31	-	-	-	38	27	30	-
		Industry (innovative manufacturing firms)	-	7	-	-	32	-	23	-	-	30	42	-	7	*67*
D'Este and Patel (2007)	UK	STEM academics	25	-	-	56	56	-	45	21	65	-	-	43	-	-
Muscio (2013)	Italy	STEM academics	-	-	2	22	40	-	12	1	13	-	5	3	2	-
DEA (2014)	Denmark	Academics in all disciplines	32	-	20	48	32	-	80	-	-	-	83	-	-	-
			Importance (% of respondents) deemed channel important for university-industry knowledge transfer)													
Meyer-Krahmer and Schmoch (1998)	Germany	Academics in science-based fields	-	-	-	52	56	-	74	-	56	71	60	60	39	-
Cohen et al. (2002)	USA	R&D units in manufacturing industry	18	10	-	32	21	41	18	-	35	36	-	-	6	20
Bekkers and Bodas Freitas (2008)	The Netherlands	STEM industries	71	32	32	35	44	76	60	33	67	73	-	14	35	69
		STEM academics	38	33	47	55	55	90	80	44	89	91	-	36	47	89
			Relative importance (% of total importance ascribed to each channel)													
Schartinger et al. (2002)	Austria	Industry (innovative firms)	-	-	5	22	22	-	15	-	-	-	14	7	6	-
Agrawal and Henderson (2002)	USA	Professors in engineering	7	7		26		18	12		5	6	9			17

Importance legend: *Unimportant* (light grey) · Medium important (dark grey) · Important (black) · --- Not considered in the study centrated than the knowledge spillovers through patent disclosures (Mowery & Ziedonis, 2015). Other debates concern how this intellectual property in turn could be exploited by university staff or students themselves in university spin-offs (Shane, 2004), thereby leading to an even stronger geographical concentration of impacts (Ponds et al., 2010). Universities have established specialised technological transfer offices to facilitate this process (Debackere & Veugelers, 2005). These channels have received a lot of attention by showcasing top-tier universities—such as the University of California, Columbia University, and Stanford University—that were able to generate considerable revenue from their commercialisation activities (Mowery et al., 2002, 2001).

However, patenting, licensing, and spin-offs represent only a rather small proportion of the knowledge exploitation activities of universities (Norn, 2016). In addition, such activities tend to be concentrated only in a few institutions, and there is no evidence that these knowledge exploitation activities are profitable for more than the top few institutions (Geuna & Nesta, 2006). Even for a high-ranked university such as MIT, patents were considered to be of little importance for knowledge transfer (Agrawal & Henderson, 2002). Further, the importance of patents tends to be characterized by a strong sectoral concentration, with particular a strong importance for the pharmaceutical sector (Cohen et al., 2002). Nelson (2001) refers to it as being a myth that universities generate considerable income from patenting and licensing, stating that the costs for technology transfer are likely to outweigh this revenue. Further, it has been argued that the focus on patenting and spin-offs clashes with the open character of universities and delays the open sharing and publication of research findings (European Commision, 2002). Hence, academics, who tend to be primarily interested in furthering their research agenda rather than commercialising their knowledge (D'Este & Perkmann, 2011), are more inclined to turn to other ways in which they can create societal impact with their research (Perkmann et al., 2013). Patenting, licensing, and spin-offs, as indicated by the greyscale markings of cells in Table 1, are deemed to be of only peripheral importance to the economic impact of universities by university and industry representatives (Agrawal & Henderson, 2002; Bekkers & Bodas Freitas, 2008; Cohen et al., 2002; D'Este & Patel, 2007; Schartinger et al., 2002, 2001). Norn (2016) uses the phrase *"what lies beneath the surface?"* to refer to the wide spectrum of alternative channels that have begun receiving more attention in the literature only since the early 2000s.

1.5.2 Research services

Contract research and consultancy, which are services bought from universities by external actors, are deemed to be an important channel for university–industry knowledge transfer. The usual distinction made between these two channels is that contract research is more open-ended and requires the generation of new knowledge, while consultancy merely exploits the available knowledge within universities (Perkmann & Walsh, 2007). Research services also tend to take place over a proximate geographical distance (Muscio, 2013). Further, Schartinger et al. (2002) found a spatial bias in firms' selection of universities for contract research, which might be due to the lower transaction costs involved in interaction with a local university.

With external direction for the research, such arrangements offer relatively little academic freedom, as academic actors are expected to direct their research according to the demands of industry actors (Eisenberg, 1987). Hence, these channels are deemed to be of less academic value. Yet, Van Looy et al. (2004) indicated higher publication output among researchers involved in contract research, with no bias towards more applied research, as would be expected if industry would become the main driver of the research interests of academicians.

However, these interactions may be regarded as superficial, as firms buy a service from a university without an actual interaction taking place. It could be argued here that universities, as publicly funded actors, pose an unfair competition by offering services that could be offered by private consulting firms. Another issue is that the importance of contract research tends to be concentrated only in a few sectors (Cohen et al., 2002). The main concern regarding the provision of research services is the limited transfer of tacit knowledge (Schartinger et al., 2002). Absorbing such knowledge is crucial; otherwise, the investments are similar to the proverb 'if you give a man a fish, you feed him for a day—if you teach him to fish, you feed him for a lifetime'. Absorbing tacit knowledge and developing an understanding itself as a firm is crucial, since knowledge must be adapted to the firm-specific context (Nidumolu et al., 2001). The spatial proximity of research services enables some of the face-to-face interaction that is required for the transfer of tacit knowledge; however, the actual transferring process requires intensive interaction (Nonaka & Takeuchi, 1995). Yet, this is lacking with the little relational involvement in research services (Perkmann & Walsh, 2007), since the university is the prime actor working on the product and there is little or no collaborative knowledge development.

1.5.3 Research output

Publications, being the traditional output of the research mission, are also considered by several authors to be an important channel for transmitting university knowledge to industry (Bekkers & Bodas Freitas, 2008; Cohen et al., 2002; Meyer-Krahmer & Schmoch, 1998; Norn, 2016; Perkmann & Walsh, 2007; Schartinger et al., 2002). Although scientific publications can easily be distributed across the globe, the geographical bias of citation networks nevertheless suggests that these outputs are also, to a certain extent, restricted by geographical distance (Pan et al., 2012). Moreover, industry readership is geographically concentrated, as indicated by geographical bias in scientific citations in industry patents (Narin et al., 1995). These geographical biases are particularly prevalent in the early years after publication and seem to fade away to a certain extent over time (Feldman, 1999). Nevertheless, geography appears to matter, possibly due to social ties and cognitive proximity, both of which are crucial for the dissemination of tacit knowledge which can play a crucial role in interpreting the codified knowledge in publications (Howells, 2002).

In this manner, the regional impact of scientific publications is likely to be related to participation in research collaborations, employment of human capital, and informal interactions through which universities function as knowledge resources for the local company base. Perkmann and Walsh (2007) make a similar claim stating that scientific publications can accompany all other university–industry knowledge transfer channels. Networks created through research collaborations, informal interactions, and human capital can help explain regional bias in the uptake of the research output.

1.5.4 Research collaborations

Collaborative research endeavours offer university and industry actors a setting that can enable the interactive co-production and sharing of knowledge (Canhoto et al., 2016). Similarly, joint research centres or facilities enable the joint development of knowledge. Co-production entails that both university and industry actors recombine their expertise and together create new knowledge or applications (Van De Ven & Johnson, 2006). Although both academia and industry are characterised by globalisation, there remains a strong bias towards geographically and institutionally proximate collaboration (D'Este et al., 2013; Hoekman et al., 2009). Companies prefer to collaborate with a proximate university partner of sufficient quality than to work across larger distances with a university partner with a stronger scientific track record (Fitjar & Gjelsvik, 2018). In addition, geographical proximity is particularly important in short-term applied projects, in which trust and transaction costs might play a decisive role (Broström, 2010). While geographical proximity clearly drives down interaction costs, geographical proximity is neither a necessary nor sufficient condition per se and its prime benefit stems from its correlation with other proximities—such as cultural and social (Boschma, 2005). Participation in university–industry collaborations can decrease the social distance and enable subsequent informal exchange of knowledge at the university–industry interface (Østergaard, 2009). Research collaborations are also considered to be more suited to the exchange of tacit knowledge than the previously discussed channels (Schartinger et al., 2002), owing to their interactive character. Hence, university–industry collaborations are a vital channel for realising university–industry knowledge spillovers for the development of sustainable competitive positions.

1.5.5 Informal interactions

Informal interactions, defined as interactions at the individual level in which contracts and funding are not the primary aims, have also received extensive coverage in the literature (Bekkers & Bodas Freitas, 2008; Cohen et al., 2002; Meyer-Krahmer & Schmoch, 1998; Perkmann & Walsh, 2007). They may occur during workshops and conferences, thereby creating possibilities for interaction and thus playing an important role in building networks (Field, 2003), to subsequent quick queries with personal contacts with whom ties have been established. Collaborations on teaching—such as guest lectures, internships, and joint supervision—also tend to have an informal character. Several studies emphasize the importance of these informal and, hence, often localised connections for knowledge transfer (Bekkers & Bodas Freitas, 2008; Cohen et al., 2002).

Although the value of these interactions is acknowledged, studying them is complicated not only by their ambiguous, heterogeneous and broad definition but also by the limited data availability on informal interactions, since these are, by definition, undocumented. Furthermore, Perkmann and Walsh (2007) also state that these informal connections are more likely to be accompanying other interaction channels. Research collaborations not seldom lay the foundation for later informal interactions (Østergaard, 2009), while human capital exchange can also foster future informal interactions. This might also explain why when the relative importance of the knowledge transfer channels is assessed, the informal channels are not deemed as important anymore (Agrawal & Henderson, 2002); their value lies in their co-occurrence with other channels. Further, informal university–industry interactions can also play an enabling role for the establishment of university–industry collaborations (Ponomariovi & Boardman, 2012). Hence, informal connections do not tend to take place in isolation from research collaborations and human capital transfer. For example, the informal connections of graduates with their former university may lead to the establishment of later university-industry collaborations (Drejer & Østergaard, 2017). Hence, understanding the role of human capital for university–industry knowledge transfer is of importance.

1.5.6 Human capital

Much of the extant research considers human capital as a channel for university-industry knowledge flows (Agrawal & Henderson, 2002; Bekkers & Bodas Freitas, 2008; Cohen et al., 2002). By transferring and upgrading human capital, companies strengthen the available tacit knowledge in the organisation.

Companies that are aware of and focus on developing their human capital also turn to universities for acquiring training for their staff. Also the mobility of employees has been extensively discussed as a channel for transferring tacit knowledge between organisations (Almeida & Kogut, 1999; Power & Lundmark, 2004). In academia, the transfer of scientists to industry can be an important step in commercialising academic knowledge (Zucker et al., 2002). Labour mobility also tends to be regional in scope (Power & Lundmark, 2004), and employees would generally rather commute than move to a neighbouring region (Eliasson et al., 2003). Although university–industry staff transfer can play a role in university-industry knowledge transfer, tenured positions and the stability they offer may get lost when moving to industry, thereby reducing the mobility of tenured academics compared to their industry peers (Crespi et al., 2007). Further, academics are motivated by a research logic rather than be driven by a commercial logic (Bruneel et al., 2010; D'Este & Perkmann, 2011), although the latter might be necessary to thrive in industry. Hence, there is a difference in institutional logic between academics and industry, which may pose a barrier to university-industry labour mobility. Owing to the previously mentioned reasons, most studies do not consider the training of industry staff and labour mobility to be an important channel for university–industry knowledge transfer (Bekkers & Bodas Freitas, 2008; Cohen et al., 2002; Muscio, 2013; Schartinger et al., 2002).

Yet, PhD students, as junior academics, are increasingly expected to move to industry due to the higher rate of growth in the number of doctorate holders compared to employment opportunities in academia (Larson et al., 2014). This results in the majority of them finding employment outside academia (Auriol, 2010); even a substantial proportion of doctorate holders in the social sciences and humanities find employment in industry (Drejer et al., 2016). Industrial PhD programmes, which are becoming more popular, foster a more business-oriented mindset among these students, who exist at the intersection of academia and industry (Wallgren & Dahlgren, 2007). PhD graduates are even seen as bridges for facilitating trust and interaction between industry and academia (Slaughter et al., 2002). While PhD graduates tend to be highly mobile owing to or indicated by previous mobility (Auriol, 2010), a considerable proportion opt for employment in the region in which they completed their degree (Drejer et al., 2016).

However, PhD graduates account for only a small proportion of university graduates (OECD, 2019a). In fact, a few authors may consider master's and bachelor's graduates even too omnipresent to include in their definition of university–industry knowledge transfer channels. The importance of graduate human capital for regional industrial development has led to it being used for explaining inter-regional difference in innovation performance (Faggian & McCann, 2009b). As argued earlier, graduate labour is important for gaining competitive advantages in the knowledge-based economy. Although graduates are more mobile than the general population and in some countries even the majority moves out of the region after graduation, nevertheless a considerable part of the graduates is retained within the region of study (Faggian et al., 2007; Evers, 2019). Not only does this human capital have a regional impact, the impact also tends to be rather long-term when compared to other channels, like research collaborations, thereby having a long-term impact on university-industry knowledge transfer.

1.6 Research focus

Previous sections have discussed—by elaborating on their perceived importance, capability of transferring tacit knowledge, and regionalised character—the relevance of these university–industry knowledge transfer channels for regional industrial development. This leaves us with research collaborations and graduates, including both undergraduates and graduates at the doctoral level, as key channels to be studied in this thesis. Here, we do not deny the existence of the value of the other channels but hope to have argued for this selection. In order to gain a better understanding of the role of university–industry interaction—which occurs through these channels—in regional industrial development, this thesis is guided by the following question:

> **What is the role of university–industry research collaborations and graduate production in the impact of universities on regional industrial development?**

The selection of these channels must not be understood as two separate theses in one; the combined study of these channels is done with a specific purpose. The two channels of research collaborations and graduate production are the extension of the first and second university missions, and these are combined into one institution for a reason—synergies exist between these missions, as those that exist between the graduate and collaboration channels. Graduates can lay the foundation for new collaborations (Drejer & Østergaard, 2017), while collaborations can lead to the recruitment of graduates (Broström, 2012; Harryson et al., 2007).

This thesis is a collection of six papers—Papers A, B, C, D, E, and F— that focus on the role of university–industry interaction for regional industrial development, paying specific attention to the role of research collaborations and graduates. The next section provides an overview of the papers and positions them within the literature. Then, the empirical context and methodological considerations are discussed. Finally, the concluding section of this synopsis discusses the contributions of the research, policy recommendations, and avenues for further research.

2 The role of universities in regional industrial development

This section elaborates the wider theoretical context of this research as well as provides insights into the findings of the papers included this volume. The papers are divided into three parts following Part I, which is this synopsis; Part II includes Papers A and B, which focus on the graduate production; Part III includes Papers C and D, which focus more on research collaborations while still acknowledging that these channels are largely intertwined; and Part IV consists of Papers E and F, which provide some qualitative evidence to support both these discussions.

2.1 Part II: Graduates and regional industrial development

As discussed in the previous section, human capital is one of the most common channels for transferring the knowledge present in universities to the local industries by equipping graduates with human capital (Thanki, 1999). In line with this, several studies indicate human capital production as a factor supporting economic development and its uneven distribution ascribing it a role in explaining inter-regional differences in economic development (Faggian & McCann, 2009a; Gennaioli et al., 2013). Paper A assesses the impact of establishing a university on the labour market for graduates, followed by Paper B that addresses the alignment of universities' teaching mission with the regional industries.

2.1.1 Paper A: The impact of the establishment of a university in a peripheral region on the local labour market for graduates

There is an uneven spatial distribution of university graduates, with a concentration of graduates in the more central regions that host universities (McHenry, 2014; Tödtling & Trippl, 2005). This is partially due to the fact that young people in regions that lack a university are less likely to attend university (Frenette, 2009) and the ones who do attend university need to leave the region, often to not return after graduating (Faggian et al., 2007). The latter can be due to the fact that the cities hosting a university have a more attractive labour market, have more of the creative class attributes that high-skilled individuals tend to enjoy (Florida, 2005), or have built new social networks in their region of study that inhibit them from moving back to their former home region (Berck et al., 2016; Hoffman et al., 1998). These developments led to a thin supply of graduates on the labour market in these more peripheral regions, limiting the access of the regional industries to the required human capital and hence, limiting their development (Tödtling & Trippl, 2005).

This situation has all the ingredients for setting into motion a vicious circle in which industries located in regions with universities can develop faster and thereby create a more attractive labour market, while regions in the economic periphery would be excluded from these dynamics, thereby leading young people to leave the region to study and finding employment. Confronted with these dynamics and often encouraged by local lobbying, policymakers in peripheral regions have considered the establishment of a university as a policy intervention to eliminate this barrier to economic development (Charles, 2016).

This led to a new wave of university and branch campus establishments, particularly during the 1970s and 1980s (Schofer & Meyer, 2005). These new institutions increased university attendance among the local youth (Frenette, 2009) and often resulted in rapid growth in the student population. Ideally, the fast-growing supply of graduates would be absorbed by regional industries and thereby support the development of such industries, but industrial development tends to be a rather gradual, long-term process (Maskell & Malmberg, 1999), which makes it uncertain whether the process can keep pace with the rapidly growing supply of graduates entering the regional labour market. If these dynamics lead to an oversupply of graduate labour in the labour market, wages could fall or graduates could leave the region in search of employment. In order to provide insights into these dynamics, Paper A focuses on the following question:

> **What impact does the establishment of a university in a peripheral region have on the local labour market for graduates?**

Several studies have studied how universities impact the labour market and regional economic development (Faggian & McCann, 2009c; Saarivirta & Consoli, 2014), although the availability of data places several constraints on these analyses. While developed countries have witnessed a wave of university establishments in the 1970s and 1980s (Schofer & Meyer, 2005), most of the available data sources do not cover this period and are often limited to a sample of the total population at one moment in time and only capture geographical mobility. Further, some recently established universities are not the first universities in their region, which complicates isolation of the impact of a single university.

In order to overcome these empirical barriers to studying the impact of the establishment of a university on the regional graduate labour market, this paper utilises micro-level data from Statistics Denmark to provide insights into the educational status, geographical mobility, and wages of the total Danish population dating back to 1980. During this time period, Denmark witnessed the establishment of a few smaller universities, many of which were later integrated into existing educational institutions. The only university founded since 1980 that is still independent is the IT University of Copenhagen, which was established in 1999 (ITU, n.d.). However, Copenhagen is the most central region of Denmark and already features several universities, so this university is not suited for answering the above question. Two of Denmark's eight universities were established in the 1970s, from which only Aalborg University is located in the economic periphery of Denmark. Graduates of Aalborg University have just begun to enter the labour market in small numbers at the beginning of the timeframe of the data, thereby allowing the assessment of how it changed the labour market in the years that followed.

The micro-level data for the case of Aalborg University reveal that the university contributed to increasing the share of graduates in the workforce and fulfilled the demand in the labour market, as indicated by wage growth similar to that of the labour market in other regions, and a growing percentage of local young people who remained in the region after graduation. In addition, the university increased its intake of students from outside the region, who then as graduates dispersed to other parts of the country, thereby, the university took up a role as a human capital provider at the national level.

The similar wage development could be indicative of the findings of Venhorst et al. (2010) who found that student performance does not play a role in the likelihood of students to move away from a peripheral region. The findings in this paper indicate that the region benefitted from the establishment of a university and, in certain contexts, universities can be used as policy instruments for regional development. However, Faggian and McCann (2009c) found large variation in the regional retention of graduates, and other studies report on regions struggling to retain the graduates of the local university (Frenette, 2009; Saarivirta & Consoli, 2014). Understanding these different outcomes is the aim of Paper B.

2.1.2 Paper B: The alignment of universities' teaching mission with the demands of regional industry

The literature thus indicates that a positive regional impact through the retention of graduates of a local university is not a given. Faggian and McCann (2009c) argue that the impact of universities might depend on the extent to which they are oriented towards the economy of their region. In other words, the extent to which the teaching mission of universities is aligned with the demands of regional industries influences the likelihood that graduates will be able to find employment that matches their educational level and specialisation. While graduates are likely to find employment if they move to other sectors and apply for jobs for which they are overeducated, doing so will reduce the economic returns on their education (Duncan & Hoffman, 1981). Although social and cultural factors can also play a role in the decision to migrate, economic reasons—like employability—tend to play a more important role in this process (Kontuly et al., 1995). Hence, graduates that are struggling in the labour market are more inclined to move away from the region and thereby not contribute to the regional industrial development.

However, universities are not likely to act like cathedrals in the desert; indeed, there are several mechanisms that connect the region's industrial specialisation and the educational specialisation of the university in the region. Through their interactions with industry, universities both develop a better understanding of industry demand while also being influenced by industry pressure and incentives to adapt their educational offerings to the requirements of regional industries (Azagra-Caro et al., 2006; Holmén & Ljungberg, 2015; Lee, 2000; van der Sijde, 2012). At the same time, regional policymakers increasingly evaluate public universities based on their capacity to serve the demands of public and private labour markets (Charles, 2016; Mason et al., 2009; Sarrico et al., 2010). This requires that graduates trained by the university must fit into the local company base, thereby ensuring that they remain in the region after graduation (Krabel & Flöther, 2014; Srinivas & Viljamaa, 2008; Venhorst et al., 2010).

These influences make it likely that universities align their teaching mission with the requirements of regional industries. Although the educational system is partially driven by students' demand for education, universities can also influence the supply of graduates by determining which programmes to offer, how many spots are available, and by marketing specific study programs. From the perspective of prospective students, joining a study programme at a university located in a region with strong industries related to their field of study provides them access to interesting internship and employment opportunities. In addition, employers from outside the region might also attach higher value to a degree obtained in such a region. Local young people might even be more attracted to these programmes by offering them the possibility to contribute to one of the regional strongholds and increase the likelihood of finding suitable employment in their home region. Opting for a degree outside the local economic specialisation decreases the likelihood of finding such a job that captures the maximal value from the skills, thereby increasing the chance of a job mismatch that is likely lead to reduced wages (McGuinness & Byrne, 2015). Further, tougher labour market competition can force graduates to search for jobs in a wider geographical area (Venhorst et al., 2010). A study on Italian peripheral regions showed that graduates in technical fields were more likely to leave due to the lack of demand for their skills in these regions (Coniglio & Prota, 2008). On the other hand, graduates that are slightly more flexible in their job search, like those from arts programmes, are less likely to move due to these dynamics (Faggian et al., 2007).

The literature describes several cases of universities that aligned their teaching missions with regional industries. These include well-known cases such as the universities in the Boston area, which supported the development of the biotechnology cluster (Breznitz & Anderson, 2005; K. Porter et al., 2005), and Stanford's role in the evolution of Silicon Valley (Adams, 2005; Saxenian, 1996). Studies have also reported smaller, less well-known examples of these dynamics in which companies assumed an active role by supporting study programmes and pushing universities to deliver the graduates they need (Ahoba-Sam et al., 2018). While these studies provided insight into the dynamics of this interdependency present between the human capital provided by the university and the regional industrial development, little is known regarding whether these are unique cases or if these observed dynamics are more general. Further, this also indicates a need to understand the effects of a possible absence of these dynamics on the regional retention of graduates. In order to study this, Paper B aims to answer the following question:

> **To which extent do universities align their teaching mission to the regional industrial specialisation?**

Ideally, a study aimed at answering this question would assess the regional specialisation of universities in particular study fields and relate that to the regional specialisation in industries that tend to employ the graduates from these study fields. While a few studies have attempted to do so, empirical challenges often limit these to only assessing differences at the level of broad classifications—like STEM graduates (Stewart, 2017) or large industry groupings. These limitations are understandable, given the small sample size and the other data constraints that limit a detailed analysis. Further, the relatedness between educational fields and industries is often difficult to predict.

Overcoming these empirical barriers requires micro-level data on the extant dynamics. The aforementioned Danish micro-level data set provides such data, thereby enabling assessment of the relationship between the specialisation of the teaching mission of the universities in a region and the regional industrial specialisation. For the labour market regions in Denmark that host at least one university, this paper assesses the relationship between the region's industrial specialisation and the specialisation of regional universities in study fields related to these industries.

The analyses revealed that in all the labour market regions, universities adapt their educational offerings to the industries present in the region, meaning that certain fields of study are more likely to be offered by universities in regions with a strong industry demand for graduates from these study fields. The universities in these regions are also more likely to offer new educational programmes related to industries in their region earlier than other universities and have a larger share of graduates in study fields related to regional industries. Further, the analyses indicated that misalignment of a university's educational mission and the regional industries—the university offers fields of study for which there is too little industry demand—fuels the outflow of graduates from the region, thereby limiting the regional impact of the university.

The findings of this study indicate that the teaching mission of universities tends to be closely aligned with the industries present in their region of location. Whereas several previous studies have discussed the existence of these dynamics in case studies (Adams, 2005; Saxenian, 1996), this paper has made an attempt to conduct a quantitative investigation of these dynamics. The study also adds to the literature on graduate mobility. The fact that graduates move away from peripheral regions to study elsewhere and never return (Faggian et al., 2007) is often blamed on the underdeveloped character of these regions or the social capital developed during the study period that prevents graduates from moving back home (Berck et al., 2016; Huffman & Quigley, 2002). However, the findings of this study offer an alternative and additional explanation: the region to which the individual moved to study may have an above-average industrial specialisation in the field in which they obtained a degree, thereby creating an actual obstacle to return migration. Further, intra- and inter-regional differences in the mobility of graduates could potentially be explained by differences in regions' educational overspecialisation.

2.2 Part III: Collaborative research and regional industrial development

As discussed in the introduction, research collaborations are an effective means to transfer tacit knowledge from universities to the industries in a region. Paper C provides in-depth insight into how various forms of research collaborations, like research centres, have led to co-evolvement dynamics between Aalborg University and the region of North Denmark. Paper D adopts a firm-level perspective and assesses how a research collaboration with a university affects a firm's recruitment strategy regarding university graduates.

2.2.1 Paper C: Co-creation of localised capabilities between universities and nascent industries

Paper B presumed the existence of mechanisms linking the specialisation of universities' teaching mission to the industrial specialisation of their regions. However, little attention has been paid to the wider context in which this process takes place. The interdependence between regional industries and universities is likely to extend beyond the teaching mission and can include a variety of the different university–industry interaction channels (Bekkers & Bodas Freitas, 2008). Through these channels, universities can play a role in facilitating the development of localised capabilities—which are regional characteristics that are difficult to replicate in other locations—and support the sustained competitiveness of regional industries (Maskell et al., 1998). Learning capabilities, informal institutions, and the configurations of actors that facilitate their creation are difficult to move or replicate across space (Lundvall, 1992).

Replicating the success of cases like Stanford, which played an important role in the development of Silicon Valley, or the involvement of universities in the Boston area in the emergence of a biotech cluster in the region has been a widely debated issue in policy circles. However, attempts to replicate such localised capabilities have been criticised for not sufficiently taking into account the importance of local actors and contexts in the process (Maskell et al., 1998; Palazuelos, 2005). Industrial development policies in other regions could benefit from a deeper understanding of the interplay between the processes that facilitate the creation of localised capabilities.

Localised capabilities result from feedback loops, which implies that an actor modifies their strategies in response to what other actors do within the same region and that the interactions between them lead to the co-creation of localised capabilities (Maskell et al., 1998). Paper C argues that this also applies to the role of universities in stimulating regional industrial development: universities can support the creation of localised capabilities in their home regions with a wide range of activities as a result of feedback loops between university actions and industry developments. The intensity of university–industry feedback loops influences the extent to which localised capabilities are formed. For example, interactions that take place between universities and particular industries may support the growth of industries by providing graduate human capital and knowledge, which in turn could enhance further interaction.

In order to examine how regions can develop localised capabilities, this paper analyses how localised capabilities are co-created between universities and nascent science-based industries at the regional level. The focus is on the feedback loops that lead to, and result from, university activities—such as the creation and commercialisation of knowledge, training of students, and application of existing know-how in collaboration with external partners (Drucker & Goldstein, 2007). This enquiry is guided by the following question:

> **How are localised capabilities co-created between universities and nascent industries at the regional level?**

Some of the aforementioned studies on Silicon Valley and the Boston area already touch upon similar dynamics (Breznitz & Anderson, 2005; K. Porter et al., 2005; Saxenian, 1996). However, they and the literature in general tend to focus on the more central regions and are biased towards success cases (Wiig & Wood, 1995). More insight is required to understand how such co-creation processes unfold in the context of peripheral regions, since many of these regions are confronted with a downturn in their traditional industries and are in need of the development of new industries. Thus, this study attempts to understand the dynamics of not only success cases but also less successful examples of the interactions between university and industry intended to realise localised capabilities in nascent industries in peripheral region context.

The setting for this paper is the North Denmark region and its university located in Aalborg. It relies on two case studies: 1) The success story of the interaction between Aalborg University and the ICT industry, and 2) the interaction between Aalborg University and the biomedical industry, which did not deliver the expected results. The case study method enables one to trace how the development of each industry might have stimulated actions by the university over time and vice versa (Yin, 2014). The cases are selected based on their outcomes: both involve science-based industries with a strong connection to the local university (Stoerring, 2007; Stoerring & Dalum, 2007), yet they had differing levels of success in forming localised capabilities. The goal here is to understand the processes that resulted in the differing outcomes (Ragin, 2009). The case studies are conducted with a combination of qualitative and quantitative research methods. The qualitative methods include analysis of secondary sources and semi-structured interviews conducted with representatives of both sectors and the policy domain, while the quantitative methods include analysis of descriptive macro-data from Aalborg University, descriptive macro-level data available online from Statistics Denmark, and the aforementioned Danish micro-level data.

Since their early days, the two industries have tapped into the educational, research, and entrepreneurial activity of Aalborg University in order to develop innovative capabilities that could support their growth. In turn, the university has increasingly invested in activities to support these industries. However, the outcome of university–industry interactions have differed between the two industries. While the workforce of the ICT industry enjoyed considerable growth until the early 2000s, the biomedical industry expanded to a much lesser extent. This difference in outcomes provides an excellent opportunity to investigate how localised capabilities are co-created. Feedback loops are considered to be of vital importance in this process. As the ICT industry grew, demand for graduates was created, which the university began filling (as expected given the findings of Paper B). This, in turn, allowed the ICT industries to grow, thereby creating more demand for graduates and allowing the university to expand its activities in this area. Similar feedback loops could be observed for collaborative research. Yet, the size of the nascent industry during university–industry interaction also influenced the extent to which these feedback loops led to the co-creation of localised capabilities. The larger the industry, the greater the number of industry actors and the greater the possibilities for university–industry interaction. This caused the university to dedicate more resources to activities that contribute to the development of localised capabilities that are relevant to the industry. The smaller size of the biomedical industry appears to have prevented the co-creation of localised capabilities through university–industry interaction; if businesses lack the critical mass required to grow, the university's actions are unlikely to generate the localised capabilities required to guarantee the competitiveness of the industry and its growth.

The insights delivered in this paper contribute to the university–industry interaction literature on the regional impact of a university (Charles, 2006; Uyarra, 2010), thereby offering a contextualised explanation of how university–industry feedback loops stimulate the development of specific industries. The importance of strong bottom-up dynamics on the industry side might pose a challenge to policies that rely on universities as the main drivers of regional development. Both the university and industry appear to be necessary for the development of localised capabilities, thereby reiterating the point of smart specialisation policies that building on already-existing developments is key (Asheim, 2014).

2.2.2 Paper D: The effect of university–industry collaborations on firm-level human capital

As argued in Paper C, university–industry interaction, such as teaching and third mission activities, can influence the development of industries. Drejer and Østergaard (2017) show that university graduates, who are the output of the teaching mission, can play a role in establishing university–industry collaborations. However, graduates could also play an important role in later stages of collaboration. It is known that academics become involved in these collaborations for research-related motives, such as learning and acquiring resources for research (D'Este & Perkmann, 2011). While acquiring resources can incentivise academics to collaborate with industry, potential loss of freedom can refrain them from collaborating (Tartari & Breschi, 2012). Although there is knowledge on the motivations of academics, there is little knowledge regarding why firms want to collaborate with universities. Since there are no clear quantitative effects of university–industry collaboration on firm performance, it is presumed that firms collaborate for strategic purposes, like to strengthen their knowledge base by obtaining knowledge from the collaboration partner and their collaboration (Perkmann et al., 2011).

However, the sharing of knowledge across organisational boundaries can be hindered by several factors, such as differences in institutional culture (Bruneel et al., 2010), a lack of absorptive capacity (Cohen & Levinthal, 1990), the tacit nature of the knowledge (Santoro & Bierly, 2006), and the absence of social capital required for the knowledge transfer (Johnson et al., 2002). Hence, firms planning to employ their collaboration with universities to strengthen their knowledge base need to adjust according to these concerns. While there are a variety of approaches to address these concerns, most require long-term interaction and commitment of resources. Considering that knowledge is stored within people, as mentioned in the introduction section, employees could potentially play a crucial role in overcoming these barriers. Almeida and Kogut (1999) showed that the inter-firm mobility of engineers facilitated knowledge transfer between organisations. Similarly, Song et al. (2003) argue that firms can further their interests by strategically recruiting people with the required assets to facilitate knowledge transfer.

A feasible, hence attractive, means for firms to overcome these hurdles is to adjust their recruitment strategy to focus on individuals who possess the assets required for knowledge transfer. Specifically, firms could benefit from focusing their recruitment efforts on university-level human capital to overcome both the institutional culture and absorptive capacity barriers. Firms could aim to acquire some of the tacit knowledge and social capital by focusing on the recruitment of graduates specifically trained by their university partner. Paper D addresses the following question to provide insight into these dynamics:

> **What is the impact of university–industry collaborations on firm-level graduate human capital?**

A few studies have provided qualitative insight in some of these dynamics (Kunttu, 2017; Siegel et al., 2003; Broström, 2012; Harryson et al., 2007). However, quantitative studies on these dynamics have often been complicated by the available data. In the few cases in which employment data includes detailed data on the educational background of employees, there is often no data on the university–industry collaborations in which the firm is involved. Even when this is the case, university–industry data is often limited to a binary question regarding whether a company collaborates with any university. Understanding the above-described dynamics requires a more detailed data set that includes detailed employment and educational data as well as detailed data on the universities with which the firm is collaborating. In addition, it is important to include longitudinal data that enables the development of the workforce, and thereby their recruitment, of individual firms to be tracked over time.

Fortunately, the Danish version of the Community Innovation Survey (CIS) contains such questions on university–industry collaboration, and it can be linked to the aforementioned micro-level data on individual-level employment and educational backgrounds. This enables a comparison of the recruitment behaviour of firms that collaborate with a university with that of non-collaborating firms. Matching analyses are run to prevent endogeneity from driving the results.

Analysis of the hiring behaviour of Danish firms that collaborate with a university reveals an increased hiring of university graduates by these firms compared to their non-collaborating peers. They are also more likely to be involved in the recruitment of PhD graduates. By attracting these graduates, it is presumed that firms are better positioned to overcome the absorptive capacity barrier. Further, firms tend to focus their hiring of graduates on graduates trained by their university partner, which could be interpreted as a signal that this provides them with social capital and tacit knowledge that is specific to their university partner, which could further facilitate knowledge transfer across organisational boundaries.

The hiring of university graduates could be part of the increased investments in R&D and expansion of R&D departments following a university–industry collaboration, as described by Scandura (2016). By attracting these graduates, firms are better positioned to overcome barriers of culture and absorptive capacity, which Bruneel et al. (2010) indicate as barriers to successful university–industry knowledge transfer.

2.3 Part IV: Further insights into university–industry knowledge transfer channels

This part contains two papers that are, to a certain extent, related to the papers in the previous parts but are more qualitative and based on data from different contexts. They provide more in-depth insights and contextualise some of the findings. Paper E discusses the knowledge sharing in innovation projects in which universities also participate. Paper F studies how PhD graduates make the transition into industry.

2.3.1 Paper E: Knowledge sharing in smart grid pilot projects

As argued in Papers C and D, university–industry collaboration can be an important means for universities to support regional industries and, thereby, regional industrial development. Over the years, a variety of funding instruments have been developed to support firms participating in these collaborations (Feldman & Kelley, 2006). Pilot projects, in which universities and private actors jointly experiment with and demonstrate new technologies, are one such instrument (Billé, 2010; Turner & Müller, 2003). The underlying justification for providing public funding for these support mechanisms is to counter two system failures. First, while firms can benefit from these collaborations at the individual level, knowledge spillovers can offer other economic actors the opportunity to also benefit from such interactions (Aghion & Jaravel, 2015). While spillovers constitutes a public return, the collaboration decision of the firm is primarily based on the private returns that it can appropriate, which results in underinvestment in these collaborations from a public viewpoint. The second motivation for financial support is that policymakers can use it when adopting mission-oriented R&D policies to achieve strategic priorities that are not addressed by the market (Mazzucato, 2018). Specifically, policymakers can use funding instruments to encourage firms to invest in research aimed at addressing particular (societal) challenges. However, over the past few decades, numerous questions have been raised about the public returns on these public investments (Salter & Martin, 2001).

An increasingly popular policy narrative is that knowledge generated through publicly funded collaboration must increase the knowledge of the entire sector, thereby implying that generated knowledge must be disseminated beyond the context of the collaboration. In order to realise a societal impact, knowledge generated in these collaborations must spill over beyond the context of the firm to other actors in the same region or country.

Even though governmental funding programmes typically aim to realise these spillovers by advocating for knowledge sharing, they often lack a clear notion of what kind of knowledge spillovers are intended and how they should occur. This leaves knowledge sharing as largely a black box. This lack of understanding is unsurprising given the complexity of knowledge sharing as a concept. Knowledge sharing might entail recombining the knowledge of multiple partners or exchanging or disseminating knowledge (Nahapiet & Ghoshal, 1998). Actors in government-funded projects can share different kinds of knowledge (Hau et al., 2013) through several mechanisms (McDermott & O'Dell, 2001) while being constrained by a variety of barriers (Riege, 2005). Paper E aims to increase the understanding of these dynamics by answering the following question:

How is knowledge shared in public-funded pilot projects?

A few studies have discussed the dynamics of pilot projects (Naber et al., 2017) and the wide variety of channels for knowledge sharing at the intra- and inter-organisational context. Sourcing external knowledge and sharing knowledge with other actors are understood to be key for both the success of pilot projects and the realisation of social returns on public investments in these projects. Yet, the literature does not systematically discuss the different knowledge sharing levels, mechanisms, and barriers in the context of pilot projects.

Some studies on knowledge spillovers aim to adopt a quantitative approach based on patents; however, obtaining fine-grained insight into knowledge sharing dynamics requires an in-depth study of projects. In order to achieve more comprehensive and in-depth insights, this study relies on data collected from pilot projects in the Dutch smart grid sector. Interviews with project leaders and a variety of primary and secondary data sources yielded a comprehensive data set on the knowledge sharing dynamics in these projects.

Based on the data, four levels of knowledge sharing could be identified: intra-organisational, intra-project, inter-project, and project-external knowledge sharing. Specific sublevels, mechanisms, and barriers were observed at each level, thereby resulting in complex knowledge sharing dynamics. While the projects succeeded in developing knowledge, knowledge sharing between projects run by different consortium partners was rare, and project-external knowledge sharing was primarily unidirectional and involved only generic knowledge.

The findings also indicate interconnectedness between the different levels of knowledge sharing. Intra-organisational knowledge sharing can extend knowledge flows that, for example, take place at the intra-project level and disseminate the knowledge further into the organisation. This is similar to Easterby-Smith et al. (2008) who also discussed the interaction between different knowledge flows at the intra- and inter-organisational levels. We also noted that organisations tend to follow a transaction cost logic (Williamson, 1979), in which knowledge is sourced at the lowest possible cost —and hence level— possible, beginning at the intra-organisational level. When necessary, consortium partners are contacted, but other projects or external actors are seldom consulted for knowledge. Considering that the lack of knowledge creates a bottleneck that hinders the development of smart grids (Muench et al., 2014; Nemet et al., 2018), this study provides insight into the different levels, sublevels, and mechanisms of knowledge sharing, which, along with the proposed policy and managerial recommendations, can play a role in overcoming this bottleneck. This makes this research is a relevant contribution to ongoing academic and policy discussions. Our findings partially complement those of Naber et al. (2017), who emphasized the importance of understanding inter-project learning processes for up-scaling. This study adopts a more holistic approach, elucidating the levels at which the knowledge generated in pilot projects is shared as well as the mechanisms, knowledge, and barriers and means to overcome the barriers at each level.

2.3.2 Paper F: Doctoral graduates' transition to industry: Networks as a mechanism?

As discussed earlier, the shift towards a knowledge-based economy has increased the importance of human capital, particularly the demand for university graduates. Due to the democratisation of higher education in the past century, there has been an increasing supply of highly educated workers in the labour market (Auriol et al., 2013; OECD, 2016b). While the largest absolute growth of graduates trained annually is observed at the undergraduate level, the largest relative growth is observed in PhD programmes (OECD, 2016b). In fact, the annual growth in the number of PhD graduates has seen annual double-digit growth across many countries and disciplines (OECD, 2016b).

While, traditionally, doctoral education prepares an individual for an academic career, the rapid growth of doctorate holders has not been met by a similar growth in academic positions (Larson et al., 2014). This has led to an increasing trend of doctorate holders moving to employment in industry (Bloch et al., 2015). As doctorate holders constitute the most educated portion of the workforce, one might assume that they have a privileged access to the industrial labour market in knowledge-based economies. However, it is challenging to find a job at the requisite level that matches their specific expertise, which leads to reduced productivity and, hence, non-optimal labour market outcomes (Gaeta et al., 2017; OECD, 2015a). This implies that the problems doctorate holders face in the industrial labour market are not purely quantitative, as is the case with the oversupply in the academic labour market, but are more to do with finding a suitable match between their qualifications and job offerings.

These challenges call for a closer examination of what actually occurs at the university–industry interface. The career trajectories of doctorate holders have been extensively studied by addressing both internal and external factors (Bloch et al., 2015; Cañibano et al., 2019; Mangematin, 2000). However, the actual means used by doctorate holders to find a job outside academia have received little attention.

Networks are considered to be one of the most important of such means for facilitating labour market matching processes, with the network connections being the prime channel for finding a job (Granovetter, 1974; Ioannides & Loury, 2004; Montgomery, 1991). Networks make the actor aware of the available employment opportunities and provide more information on these opportunities with relatively little cost. Greater knowledge enables better evaluation of whether a job opportunity will match their profile. Similarly, employees will primarily refer jobs to individuals that they deem will fit well with the job and company. Hence, also employers reduce the risk that is inherent to the recruitment process by relying on networks in this process (Holzer, 1987).

In doctoral programs, the transferable skill of developing networks has received increasing attention over time. This focus is particularly beneficial, since networking is a skill that can also be applied in a wider context than the specific scientific area in which the doctoral student has become an expert and thereby can increase their employability (Kyvik & Olsen, 2012; Sinche et al., 2017). In addition, industry partners are increasingly involved in doctoral education, mostly by funding and hosting doctoral students through industrial PhD programmes (Roberts, 2018; Wallgren & Dahlgren, 2007). This involvement of industry contributes towards fostering networks at the university-industry interface and, arguably, facilitating the matching of the very specific PhD skills with the demands of industry. Networks traversing the university–industry interface may be key for enhancing the transition of doctorate holders to industry. Hence, Paper F aims to answer the following question:

> **What is the role of university–industry networks in the transition of PhD graduates to industry?**

Existing studies have mainly focused on the destination of doctorate holders (Auriol, 2007; Drejer et al., 2016) and provided little insight into the actual transition process between academia and industry (Cruz-Castro & Sanz-Menéndez, 2005; Manathunga et al., 2009). Thus, an in-depth understanding of how PhD graduates obtain employment is still necessary. Given the general importance of networks in labour market matching processes, this paper focuses on the role of networks in the university-to-industry transition of PhD graduates.

In order to investigate the role played by university–industry networks in the transition of PhD graduates to industry, a multiple-case study design is employed. This approach enables a contextual understanding of the university–industry transition and provides in-depth insights into the social process of networking and its complexities (Eisenhardt & Graebner, 2007; Yin, 2011). Interviews were conducted with 31 PhD holders from 6 universities in England, Norway, and Sweden.

The analysis reveals that the personal networks of doctorate holders can play a facilitating role in matching their specific scientific expertise with labour market demands. In addition, it revealed country-specific patterns and characteristics of university–industry transition after PhD graduation, with regional career paths more prevalent in Scandinavia and less noticeable in the UK.

The findings align with the work of Granovetter (1974) and others who advocate for the importance of networks in the labour market. It also aligns with Thune's (2009) argument that collaboration experiences, which facilitate the creation of networks, can play an important role in explaining the differences in career trajectories among doctorate holders.

3 Empirical context

The first four papers are all based on data from Denmark. Therefore, this section provides detailed insight into the Danish context, particularly its universities.

3.1 The Danish economy

The country of Denmark is located in Northern Europe, bordering Germany on the south and separated by sea from its Scandinavian neighbours. It is one of the most prosperous and egalitarian countries in Europe and the world

Table 2: Industrial profile Denmark

Industry	Employment in FTE (share employed)	Turnover in million DKK (share employed)
Public administration, education and health	797,753 (34.8%)	37,957 (0.9%)
Trade and transport etc.	500,370 (21.9%)	1947,180 (45.3%)
Manufacturing, mining, quarrying and utility services	301,255 (13.2%)	1267,505 (29.5%)
Other business services	231,113 (10.1%)	354,181 (8.2%)
Construction	143,315 (6.3%)	275,969 (6.4%)
Information and communication	96,154 (4.2%)	187,181 (4.4%)
Financial and insurance	78,920 (3.4%)	No data
Arts, entertainment and other services	74,907 (3.3%)	42,686 (1.0%)
Agriculture, forestry and fishing	35,660 (1.6%)	106,835 (2.5%)
Real estate	30,453 (1.3%)	80,585 (1.9%)

Source: Statistics Denmark (n.d.)

(OECD, 2019b; Worldbank, 2019). In 2018, Denmark had 5.8 million residents; approximately 1.8 million of them live in the capital region around Copenhagen and also the other part of the population tends to live in urbanised areas across the country (Statistics Denmark, n.d.). Apart from the central state, the country has five administrative regions subdivided into 98 municipalities. Its export-oriented, knowledge-intensive economy supports a strong welfare state characterised by high tax rates and a large public sector (Eurostat, 2019; OECD, 2015b). Apart from the public sector, services play a major role in the Danish economy (see Table 2).

3.2 Universities in Denmark

In 2019, 25% of the population aged 30–34 years had completed university education, thereby resulting in a highly skilled population (Statistics Denmark, n.d.). The strong prevalence of university education is facilitated by strong public investments (OECD, 2017) that enable universities to be tuition-free and provide most students with additional financial support during their studies. Just as in other countries, graduates in Denmark tend to cluster in the more urbanised areas in the proximity of universities, as is evident in Figure 1.

Denmark has a variety of higher education institutions, eight of which have full university status and can award bachelor's, master's, and PhD degrees. In 2018, just above 150,000 students were enrolled at these institutions (see Table 3). The University of Copenhagen, which was founded in the fifteenth century, is the oldest university in Denmark. Over the centuries, several new higher education institutions were established, with particular acceleration in the second half of the twentieth century. The main campuses

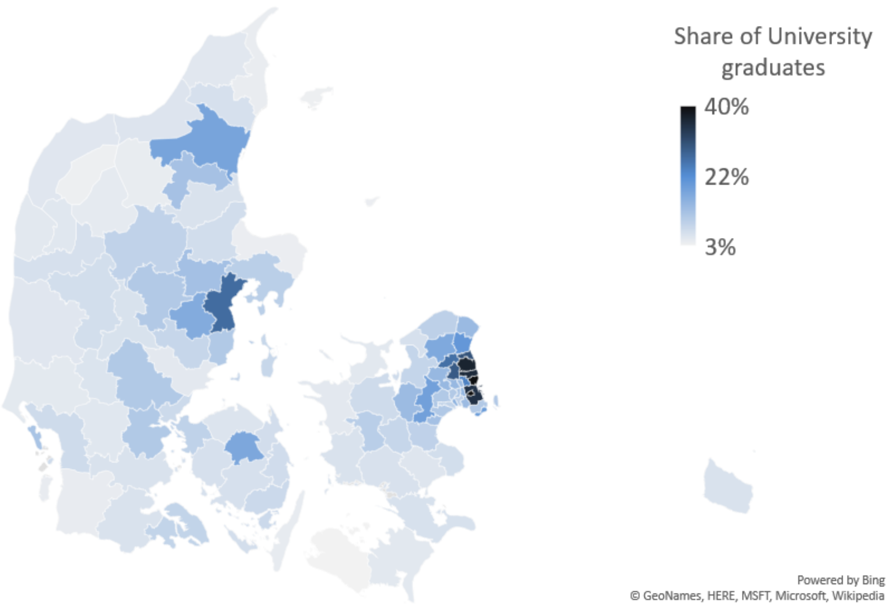

Figure 1: Share of university graduates in population aged 25-69 in 2019
Source: Statistics Denmark (n.d.)

of five of these universities are located in or in the close vicinity of Copenhagen, while the others are in Aalborg, Aarhus, and Odense. Apart from these campuses, there are several branch campuses across the country.

Universities outside the capital region have a more general profile and cover all main scientific disciplines, whereas most of the universities in Copenhagen—such as Copenhagen Business School, the Technical University of Denmark, and the IT University of Copenhagen—have strong educational and research specialisations in specific disciplines (Danske Universiteter, 2019).

Denmark presents an ideal context for studying the regional role of universities, since apart from the universities on the island of Zealand, there is little geographical overlap in the territory of universities. The administrative regions are demarcated to have at least one university and academic hospital; Aalborg University is connected to the North Denmark region, Aarhus University to Central Denmark, the University of Southern Denmark to South Denmark, and the other universities to Zealand.

The University Act, which was implemented in 2003, followed the Bologna guidelines for reaffirming the status of universities as independent, self-governing institutions, yet who are supported by public funding for conducting teaching and research activities (Carney, 2006; Ministry of Science Technology and Development, 2003). Research funding in Denmark primarily consists of basic grants for research that are allocated as lump sums to

Table 3: Universities in Denmark

	Est.	Number of Students (2018) Humanities	Social Sciences	Health Sciences	Technical and Natural Sciences	Total
Aalborg University	1974	4,293	6,103	1,814	8,187	20,397
Aarhus University	1928	9,564	12,108	4,395	7,045	33,112
Copenhagen Business School	1917	1,074	13,780	0	0	14,854
IT University of Copenhagen	1999	0	0	0	1,949	1,949
Roskilde University	1972	3,035	3,232	188	1,452	7,907
Technical University of Denmark	1829	0	0	0	11,538	11,538
University of Copenhagen	1479	9,626	11,184	7,807	9,707	38,324
University of Southern Denmark	1966	5,569	6,838	4,575	5,275	22,257

Source: Danske Universiteter (2019)

universities, which determine how the funding is distributed across departments. The amount of funding stems from historical agreements and only incremental changes can be made from year to year. In addition to the basic grants, a small part of the funding (currently amounting to 2%) is allocated based on the distribution of educational funding, external funding obtained, publishing output, and the number of PhD students that completed their theses. This funding can be complemented by grants for consultancy services for the ministries and competitive research grants managed by the research councils (Ministry of Higher Education and Research, n.d.-c).

Part of the funding for higher education is fixed at 25% of the funding received in a particular prior year. The largest proportion of funding (67.5%) is allocated based on full-time equivalent students (determined by passed examinations). More money is allocated for natural sciences students than for students in the social sciences and humanities. The other 7.5% of funding is based on the time it takes students to complete their education and their employment rate after graduation (Ministry of Higher Education and Research, n.d.-b).

In response to the Bayh-Dole Act, Denmark adopted similar policies, granting universities the rights to inventions (Stenvik, 2009). Table 4 provides a brief overview of the inventions and collaborations reported to the technology transfer offices of universities in Denmark. There appears to be a strong unequal distribution among the universities, with the Technical University of Denmark and the University of Copenhagen accounting for a major portion of commercial revenue. In addition, there appears to be a strong correlation between commercialisation and the technical character of the university, as illustrated by the Copenhagen Business School that reported no commercial-

Table 4: University industry interaction in Denmark in 2018 Reported inventions Patens

	Reported inventions	Patens granted	License agreements	Spin-offs	Research collaborations	Commercial revenue (Million DKK)	Total Revenue (Billion DKK)
Aalborg University	81	2	6	2	629	3.3	2.9
Aarhus University	68	5	10	3	559	2.4	6.6
Copenhagen Business School	0	0	0	0	107	0	1.4
IT University of Copenhagen	0	1	0	0	27	0	0.3
Roskilde University	1	0	0	0	120	0	0.8
Technical University of Denmark	117	26	13	7	1157	14.1	5.3
University of Copenhagen	78	6	26	6	361	21.3	8.9
University of Southern Denmark	36	1	3	3	302	0.9	3.1

Source: Ministry of Higher Education and Research (n.d.-a)

isation activities apart from research collaborations. However, even for the universities in Denmark with the most commercial revenue, these activities comprise less than 0.3% of the overall university revenue. In addition, research collaborations appear to be one of the main documented channels for university–industry interaction.

4 Methodological considerations

This section systematically discusses how the research conducted to answer the previously posed questions was undertaken. Hereby, the research adheres to the scientific method, in which a systematic enquiry is aimed at answering questions of relevance. While this section provides an overview of the main data sources and methods, the methodology sections of the individual papers provide more details on the specific methodological considerations and steps taken to ensure the replicability and validity of the studies. This section first discusses the research approach and is followed by a discussion of the quantitative and qualitative data sources, methods, and limitations. The section ends with a discussion of the generalisability of the research.

4.1 Research approach

This thesis adopted a pragmatic research philosophy, as described by Kelemen and Rumens (2008). This research philosophy—which originates from the thinking of philosophers Charles Pierce, William James, and John Dewey—strives to select methods based on their suitability for answering the posed research questions (Saunders et al., 2016). In line with Flyvbjerg (2006), the position is assumed that social science research must be guided by the questions of relevance rather than methodological positions.

Most of the questions raised in this thesis aim to reveal the more general patterns surrounding the role that universities play in regional industrial development. This choice was made since the literature on the topics addressed in the individual papers are characterized by qualitative accounts of the dynamics have taken place. Although these accounts provide valuable insights that also are valuable inputs for the literature reviews of the papers, insights into the overall patterns is lacking in much of the literature. One of the prime reasons for this has been the limited availability of micro-level data, which is required for quantitatively studying these dynamics. Owing to the rich availability of micro-level data discussed before (and which will be discussed in more detail in the next section), this thesis sets out for a primarily quantitative investigation of the university–industry dynamics that manifest through graduates and research collaborations. A deductive approach to theory development was used in which a review of the literature from all relevant disciplines resulted in the formulation of expectations or hypotheses. In the first four papers, these hypotheses are subsequently tested using quantitative methods, which are best suited for revealing the patterns that can be generalised to a wider population.

However, some of the concepts discussed and the mechanisms connecting them are difficult to operationalise with quantitative data. Further, such an approach tends to overlook some of the complexities of reality in which qualitative methods can provide richer and more complex insights (Saunders et al., 2016). Therefore, Papers E and F rely more on qualitative data and follow a more inductive approach. Adopting a mixed-method approach such as this combines the strengths of both quantitative and qualitative methods (Creswell, 1999). The following sections present a more detailed description of the main quantitative and qualitative data sources and empirical strategies.

4.2 Quantitative research considerations

This section first describes the two main quantitative data sources and then provides a brief overview of the analyses and limitations.

4.2.1 Integrated Database for Labour Market Research

The main quantitative data source used for the analysis is the Integrated Database for Labour Market Research (IDA) provided by Statistics Denmark. It was one of the main sources employed in Papers A, B, and D, and was also utilised in Paper C. This database provides longitudinal micro-level data on the total population of Denmark. The data are available under strict conditions that require researchers to be connected to Danish research institutions. By covering the entire population, the database provides comprehensive insights into the labour market dynamics of the Danish population, providing individual-level data on educational background, employment, wage, place of residence, and numerous other variables. The use of constant unique personal identifiers over the timeframe covered by the database (1980–2014) enables individuals to be tracked over time and variables to be constructed to measure, amongst other things, labour mobility and geographical mobility. The use of unique time constant organisation identifiers—for example, for universities or companies—enables aggregation of the data of individuals connected to these organisations. Further, for companies, it is possible to link several other data sets from the IDA database that provide data on the location of firms, industry, and a wide range of financial indicators, such as turnover and profit. Timmermans (2010) can be consulted for a thorough overview of the data available in the IDA database and how it is organised.

In comparison to other quantitative data sources, the IDA has four identified strengths. First, the granularity of the data enables assessment at the micro-level up to the level of a single individual as well as aggregation to gain insight into, for example, developments in the workforce at the firm or industry level. Second, the unique constant identifiers enable tracking of individuals and individual companies over time. Third, for most variables, data are available for the entire population (or the entire population of employed individuals in the case of employment data). Fourth, data in the database are provided through official registers, such as tax authorities for data on wages, which guarantees the reliability of the data. Yet, a few concerns must be noted. Working with data sets such as IDA require some in-depth understanding, while Timmermans (2010) provided a first introduction to the data set, consulting the online documentation and experts working with this data is key to employing this data. This is particularly relevant when a few variables have a break in the data, such as is the case for the industry variable.

4.2.2 Community Innovation Survey

The Community Innovation Survey (CIS) is a harmonised survey conducted in EU member states and EFTA states to provide insight into the innovation activities of companies, including the sources of innovation, collaborations, expenditures, and innovations brought to the market (Eurostat, n.d.). The Danish implementation of this survey, which is the one used for this thesis, has been conducted each year since 2007 by Statistics Denmark as the research, development and innovation (also known in Danish as Forskning, udvikling og innovation) survey. The sample for the survey of approximately

4,500 firms is taken from a population of 13,800 firms in Denmark. Firms are sampled based on the number of full-time equivalent (FTE) employees and sectors. All firms with more than 100 FTE employees are included in the sample, and the likelihood of firms with less than 100 FTE being included in the sample increases with the number of FTE employees and R&D intensity of the sector (Statistics Denmark, 2016). In the survey, firms are asked about their innovation and collaboration activities as well as output in the two preceding years. The survey is compulsory, thereby leading to a low non-response rate. Using the aforementioned firm identifiers, the survey results can be linked to the data available in IDA.

Of particular relevance to this thesis is data on whether firms collaborate with a university for innovation. A unique feature of the Danish implementation of the CIS is that, since 2008, it has—in comparison to most other countries—included an additional question that asked firms to specify the particular university or universities with which they are collaborating. Respondents are provided the option to select one or several of the eight universities in Denmark, a European university, and/or other universities.

There are four considerations to be mindful of regarding this data set. First, the question asking respondents to list their specific university partners is a unique feature of the Danish implementation of the survey and enables study of how firms select a university to collaborate with and how collaboration patterns differ between different universities. The availability of such detailed data has led to publications on university specific dynamics, like Drejer and Østergaard (2017). Particularly when geography is considered and the role of specific universities in a region is of interest, these data are indispensable. Second, the sampling applied for the survey significantly reduces the sample size compared to the IDA, which covers the entire population. While a sample size of 4,500 is still sizeable, it may become a concern when rare events such as university–industry collaboration are studied, particularly when zooming in on collaborations with a specific university. This issue can be resolved by combining multiple survey waves, as described in more detail in Paper D (the only paper that utilizes CIS data). Third, while respondents to the CIS are provided explicit guidelines on how the survey must be completed, those completing the survey may not have complete knowledge of all relevant aspects of their company to be able to answer all the questions. This could result in a few occasional errors, although it is deemed unlikely to be driving the results obtained from the survey. The fourth consideration is the dichotomous nature of several questions; a firm is deemed either to be collaborating with a university for innovation or not. While, in theory, this does encompass all the different possibilities, it lacks some specificity regarding the collaborations; some collaborations may be more intensive, consisting of full-time allocation of a significant part of the firm's staff, while others may require only a small part of the staff to be involved.

4.2.3 Quantitative analysis and limitations

The quantitative analyses in this study can be divided into three groups. The first is the descriptive group. In Papers A and C, longitudinal descriptive statistics are used to provide insights into developments over time. Presenting the data in tables and figures provides transparent insight into the developments taking place.

Second, Paper B uses regression analyses. The use of ordinary least squares, logistic regression, and ordinal logistic regressions aimed at providing evidence for a relationship between the independent and dependent variables in question. These methods are widely used in the innovation studies and economic geography literature. In addition to the description of these methods in Paper B, Hutcheson and Moutinho (2011), Kleinbaum and Klein (2002), and Brant (1990) may respectively be consulted for more elaboration on the use of these methods.

Owing to possible endogeneity issues, the analysis in Paper D relies on a quasi-experimental research design. The genetic matching method described by Diamond and Sekhon (2013), which is implemented in the R Matching package (Sekhon, 2011), uses an algorithm to balance the covariates of a treatment group with the covariates of a control group. In the case of Paper D, which describes this in greater detail, the treatment is defined as whether a firm collaborated with a university. After achieving balance on the covariates, the average treatment effect on the treated can be assessed, which represents the absolute difference in the dependent variable between the treatment and control groups. Since the early 2010s, this method has gained wider acceptance in the literature as a method for addressing endogeneity.

Several limitations regarding quantitative analysis must be noted. Some are due to obstacles hindering the measurement of some key concepts. For example, while numerous scholars indicate that informal networks play an important role in university–industry interactions, limitations regarding measurement imply that they have received little in-depth empirical coverage. First, different definitions exist in the literature, thereby making it difficult to conceptually demarcate between formal and informal networks. Some authors define informal networks as all interactions that are not based on organisational level contracts (Grimpe & Fier, 2010). Second, if agreement is reached on a definition, the informal dimensions of interactions remain difficult to quantify since their key characteristic is a lack of contracts underlying this interaction, which implies that there are few formal, quantifiable traces of its existence.

Even if there is a suitable way to quantitatively operationalise a variable, other considerations need to be taken into account. For example, regions can be defined in multiple ways. Some studies use administrative regions for this purpose, often because data is reported at this level of aggregation. While it is possible to use these regions in Denmark, several studies have argued that it makes more sense to use labour market regions—which are defined based on commuting patterns—as they better reflect labour market dynamics (Andersen, 2002). Thus, labour market regions are used in Papers A and B, as these papers are focused on labour market dynamics. Yet, while certain regional demarcations may be better suited for studying certain dynamics, the use of one demarcation over another does not substantially affect the findings.

Another concern is whether certain data accurately capture the variables of interest. For example, in Paper D, the sample is restricted to only innovative companies. This could be operationalised as including only the companies that provided a positive answer to the question regarding whether they introduced new innovations to the market in the past few years. Yet, this operationalisation may lead to some false positives and negatives. Therefore, the operationalization was expanded to also include other variables that gave an indication of whether a company can be regarded as innovative.

The final consideration is omitted variable bias. While the results of a statistical analysis might indicate a certain significant relationship among the variables in question, it could be that both are influenced by an omitted variable and there is no real relationship among the variables. This is particularly a concern in Paper D, where this issue is discussed in greater detail.

4.3 Qualitative research considerations

This section first describes the two main qualitative data sources and then provides a brief overview of the analyses and limitations.

4.3.1 Interviews

Semi-structured interviews were conducted to obtain an in-depth understanding of certain concepts. The semi-structured set up provided detailed insight by focusing on a set of specified topics while also making it possible for the interviewees to bring in new—and perhaps unexpected—insights (Bryman, 2012). Having the interviewees provide input on all the specified topics enables a deeper understanding of these aspects. Although obtaining generalisable insights is not the aim of these interviews, it remains important to determine the most shared insights provided by interviewees. Papers E and F primarily rely on interview data, while interviews have also been employed in Paper C.

The effectiveness of interviews heavily depends on careful selection of interviewees; therefore, the selection process is a key concern. The papers specify why and how interviewees are selected and which topics are addressed in these interviews.

4.3.2 Documents

In Papers C and E, interviews and quantitative methods were complemented by data obtained from documents. Newspaper archives were explored to find articles on historical developments that were relevant to the cases, and valuable information on the cases was obtained from policy documents. Further, the websites of the cluster organisations (Paper C) or projects (Paper E) provided insights in the cases. Paper E also utilised reports on the progress of projects, as well as internal documents on the projects.

Accessing these documents was relatively low-cost and provided in-depth insights into certain relevant developments. Yet, this yielded only codifiable insights, and there might be a bias in the data that is made publicly available. These factors must be considered when employing this data.

4.3.3 Qualitative analysis and limitations

The documents were very valuable, as they provided insight into the cases in general and helped prepare the interviews. This position of departure facilitated an atmosphere during the interviews in which the interviewees were comfortable sharing in-depth insights regarding the topics of interest. The documents also enabled triangulation of some of the insights provided by interviewees.

The interviews were recorded and subsequently transcribed; thereafter, the transcriptions were linked to the relevant concepts. In Paper E, NVivo was used for this purpose; a similar approach was used in Paper F, but it was executed with the help of a spreadsheet. This provided detailed insights into the interviewees' statements regarding these concepts. The papers provide more details on how the analysis of interview data were put into practice.

Several limitations of the quantitative analysis must be noted. One of the main concerns is the representativeness of the data. It is difficult to assess the extent to which the findings would differ if the selection of interviewees was slightly changed. However, this concern was alleviated by relying on a broad sample in Papers E and F. Just as in quantitative research, in which concepts must be operationalised, in qualitative research, the statements of interviewees must be interpreted in order to link them to the relevant concepts. Yet, the semi-structured nature of the interviews enabled the interviewer to ask for clarification if there was ambiguity in the interviewees' answers. In certain situations, the honesty of the interviewees could be a potential concern, but by granting them as much anonymity as possible, the interviewees felt comfortable sharing both positive and negative insights and experiences.

4.4 Generalisability

This thesis aims to advance the existing knowledge on the impact of university–industry interactions on regional industrial development. Ensuring that this knowledge is valuable to a wider scientific community as well as policymakers and, thus, that the findings were generalisable to different contexts was a key concern.

Worldwide, universities are considered to be key organisations in the institutional constellation of modern society (Cabal, 1993). However, there are differences in how universities are funded and governed and in the kind of roles they are expected to fulfil (Forest & Altbach, 2006). Further, there are differences within and across countries in terms of teaching quality, research output, international orientation, and industry income (CWTS, 2019; Times Higher Education, 2020). Previous findings on research interactions indicate that there is some difference between how university–industry interactions occur in the US and Europe (Owen-Smith et al., 2002). This may be explained by differences in the academic career systems in the respective countries that provide different incentive structures for career progression (Perkmann et al., 2013).

A large number of these differences are due to path dependencies and can be explained by the development of universities as institutions in these different contexts. Universities in certain countries, such as those in Eastern Europe, have attempted to reinvent themselves and break away from their past, while considerable differences within this region admittedly remain (Cabal, 1993; Scott, 2008). However, in general, there tends to be a trend towards convergence over time, thereby increasing the similarities between universities as institutions (Forest & Altbach, 2006). In Europe, this resulted in and is fuelled by the Bologna declaration, which aimed to harmonise the university systems of the 48 members of the European Higher Education Area (de Wit, 2007; EHEA, n.d.). Although differences remain, there are growing similarities in the institutional make-up of university systems.

Therefore, it is not surprising that many studies indicate similarities between countries when university–industry interactions are considered. For example, Grimpe and Fier (2010) indicate similar informal university–industry relationships in the United States and Germany. Further, the studies highlighted in Table 1 do not suggest remarkable differences among countries. Further, as revealed by the DEA (2014) survey of academic researchers, channels, barriers, and motives in the Danish context are similar to those in other countries. Yet, it must be noted that most current evidence is from a developed countries context. In a study on developing countries, Bodas Freitas et al. (2013) obtained similar findings regarding the role of barriers and support structures—in the context of university–industry interactions—in Brazil compared to developed countries. However, Brimble and Doner (2007) indicated barriers that are specific to the developing country context, and Giuliani and Arza (2009) presented a few differences between developed and developing countries. Also concerns should be noted with regard to sectoral patterns in the way firms interact with universities (Cohen et al., 2002; Lööf & Broström, 2008; Bekkers & Bodas Freitas, 2008). Hence, caution must be taken when interpreting the results of this thesis to prevent overgeneralisation.

For the findings on graduate dynamics, context is deemed to play a more important role. Countries display varying rates of geographical mobility in the labour market (Bentivogli & Pagano, 1999). Further, the graduate population is increasingly internationalising—albeit to varying extents— all across OECD member countries (OECD, 2019a). As is known that graduates who have moved before are more likely to move again (Faggian & McCann, 2009c), this development is also likely to affect the retention of graduates. While there are differences between countries and the internationalisation of the student population might influence a few of these dynamics, in most countries, national and regional economies tend to rely primarily on 'home-grown' graduates (Faggian & McCann, 2009c; OECD, 2019a). Overall, it can be concluded that, particularly in the developed world, there are more similarities than differences between countries with regard to university–industry interaction.

While the context of this research is primarily restricted to the country of Denmark, the argument of Flyvbjerg (2006) is echoed that these insights can be one of the many studies addressing these dynamics in different context and thereby contribute jointly to revealing the generalisable patterns. As all studies on the importance of universities in different countries listed in Table 1 and the studies on barriers to university–industry collaborations in different countries jointly have provided solid evidence for the general importance of channels and barriers, the studies included in this volume are also meant to be one of these pieces for fitting in and strengthening the overall body of literature on this topic.

5 Conclusion

The aim of this thesis was to assess the role of university–industry interaction for regional industrial development. The first section of this conclusion provides a brief overview of the research conducted in each paper and subsequently provides a visual explanation of how each paper captures a part of the overall picture of the role of university–industry interaction in regional industrial development. The section that follows summarizes the findings of the papers and their contribution to the enquiry and literature. This is followed by a discussion of these findings in the light of the literature, after which recommendations for further research are formulated. Thereafter, the policy implications of the research are reviewed, and the synopsis ends with a few concluding remarks.

5.1 Brief overview and relation between papers

Table 5 provides an overview of the papers included in this thesis, listing their main questions, data, methods, and findings. The six papers are divided into three parts, each of which covers a portion of the overall story of university–industry interaction in relation to regional industrial development.

Table 5: Summary of papers

	Question	Data	Methods	Findings
		Part I: Synopsis		
		Part II: Graduates and regional industrial development		
A	What impact does the establishment of a university in a peripheral region have on the local labour market for graduates?	North Denmark: IDA	Descriptive statistics	The regional economy can absorb the growing supply of graduates from a newly established university.
B	To which extent do universities align their teaching mission to the regional industrial specialisation?	Denmark: IDA	Regression models	Universities are more likely to offer degrees related to the region's industrial specialisation, offer these degrees earlier, and have a larger share of graduates in these degrees, while overspecialisation can fuel the outflow of graduates.
		Part III: Collaborative research and regional industrial development		
C	How are localised capabilities co-created between universities and nascent industries at the regional level?	North Denmark: IDA, interviews, and documents	Qualitative analyses and descriptive statistics	University–industry feedback loops play a crucial role in the creation of localised capabilities, but critical industry mass is required to fuel bottom-up dynamics.

	Question	Data	Methods	Findings
	Continuation of Table 5			
D	What is the impact of university–industry collaborations on firm-level graduate human capital?	Denmark: IDA, CIS	Matching analyses	Firms collaborating with a university refocus their recruitment strategies to university graduates, particularly graduates from the university partner and are more likely to recruit PhD graduates.
Part IV: Further insights into university–industry knowledge channels				
E	How is knowledge shared in publicly funded pilot projects?	The Netherlands: Interviews, survey, and documents	Qualitative analyses and descriptive statistics	Knowledge sharing does not occur by default. Different mechanisms and barriers play roles at the four identified levels at which knowledge can be shared.
F	What is the role of university–industry networks in the transition of PhD graduates to industry?	Norway, Sweden, and the UK: Interviews	Qualitative analysis	Personal networks play an important role in the transition of PhD graduates to industry.

Figure 2 on page 47 visualises how the papers are positioned in the broader context and how each captures a different part of the larger university–industry interaction puzzle. Paper A provides insights into the flow of graduates from universities to industry. Paper B examines how the industry profile of a region affects the teaching mission of a university. Paper C studies how university–industry interactions, incorporating both the teaching and research missions, lead to the creation of localised capabilities. Paper D assesses how university–industry collaborations refocus the firms' recruitment strategies to graduate human capital. Paper E adopts a more in-depth look at how knowledge is shared in the context of university–industry collaborations. Paper F investigates how PhD graduates make the transition into industry, paying specific attention to the role of networks.

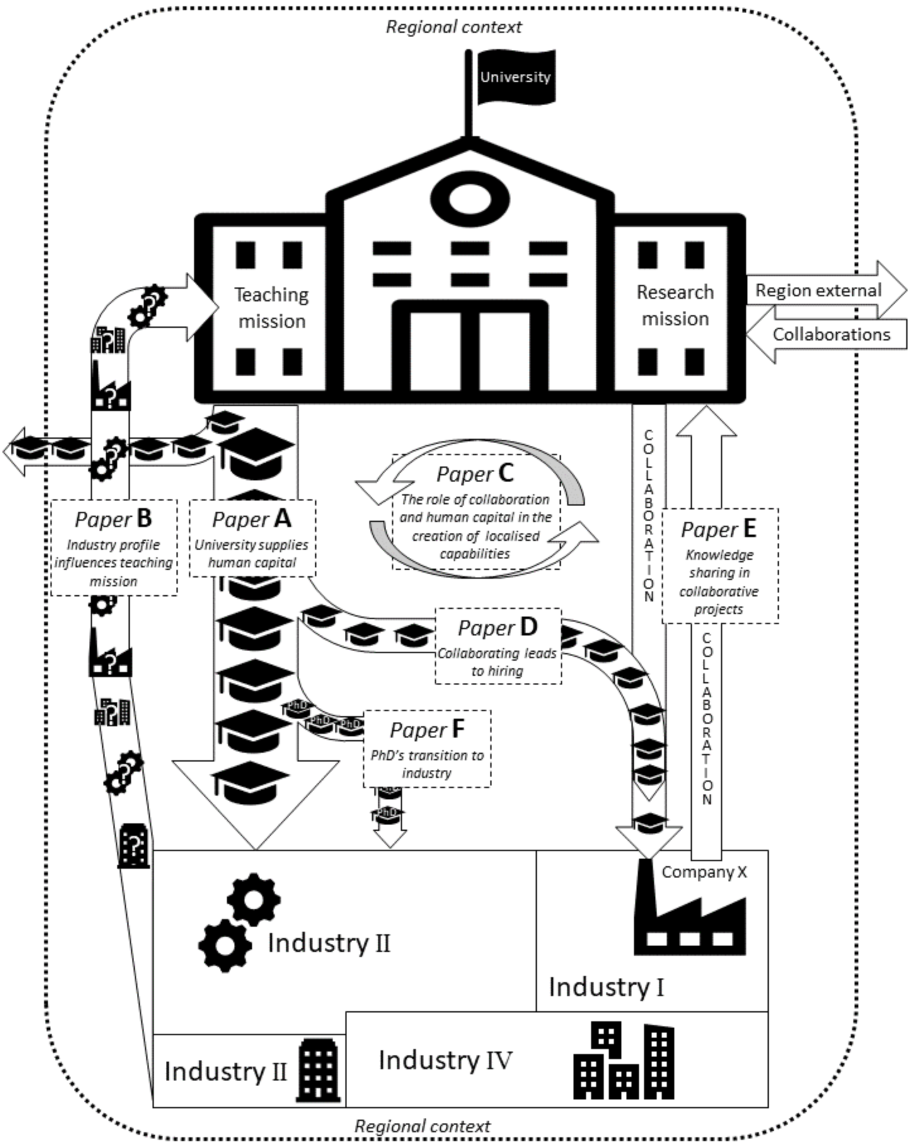

Figure 2: Positioning and interrelationships among the papers

5.2 Summary of findings and contributions to the literature

5.2.1 Paper A: The impact of the establishment of a university in a peripheral region on the local labour market for graduates

The case of Aalborg University, which is studied in this paper, analyses the impact of a university on the graduate labour market in the region. The data indicate that the strong growth in the availability of graduates did not negatively affect the graduates' earnings and retention. Further, it highlighted that the establishment of a university led to stronger relative growth of graduates in the workforce compared to other regions in Denmark. Therefore, this study demonstrates that a university can have a transformative impact on the regional workforce and strengthen the position of the region in the knowledge-based economy.

The findings of this paper align with those of several other scholars, who showed that a new university could increase the university attendance in a region and thereby increase the knowledge intensity of the workforce (Frenette, 2009). In line with Berry and Glaeser (2005), who pointed to a gravitational effect in which graduates move to places where graduates are already more present, the percentage point growth in the share of graduates in the labour market was stronger in some of the more central regions. However, Aalborg had the fastest relative growth in the share of graduates. Thus, the establishment of a university can help kickstart a region's transformation towards becoming a more knowledge-intensive economy, yet acknowledging—in line with Malmberg and Maskell (2002)—that industrial development is both an incremental and long-term process.

Outward mobility of graduates is a major concern that has been raised in the literature (Faggian & McCann, 2009c; Frenette, 2009; Saarivirta & Consoli, 2014). If graduates cannot be retained in the region, a university might only have multiplier effects on the local economy or, possibly, negative effects if the university stimulates the outflow of youngsters. Faggian and McCann (2009c) found that, in the UK, mobility among graduates reduced the regional impact of the university, but simultaneously found that the graduates of the post-1992 universities were more likely to remain in the region and contribute to its industrial development. It was argued that this heterogeneity could be explained by these post-1992 universities, which were better geared to cater the local economies. What this better adaptation to the local economies entailed often remained unclear; Paper B set out to investigate this aspect.

5.2.2 Paper B: The alignment of universities' teaching mission with the demands of regional industry

Paper B followed-up on the abovementioned gap by studying how the educational offerings of universities relate to the demands of the industries present in their region. The empirical evidence suggests that universities adapt their educational offerings to the industries in the region; universities are more likely to offer study fields related to the region's industrial specialisation and are more likely to be among the first universities to offer such degrees and have a larger proportion of students enrolled in these degrees. However, regions that overspecialise in particular degrees increase the likelihood of graduates leaving the region.

Several previous studies discussed the existence of these dynamics in various cases (Breznitz & Anderson, 2005; K. Porter et al., 2005; Saxenian, 1996). Case studies such as that of Ahoba-Sam et al. (2018) provided insight into some of the dynamics that support the alignment of the teaching mission of universities with regional industry. This study has attempted a quantitative investigation of these dynamics, thereby adding to the literature on graduate mobility. The fact that graduates move away from peripheral regions to study elsewhere and never return (Faggian et al., 2007) is often blamed on the underdeveloped character of these regions or the social capital developed during the study period, which prevents them from moving back home (Berck et al., 2016; Huffman & Quigley, 2002). An additional explanation offered by the findings presented in Paper B is that the region to which the individual moved to study may have had an above-average industrial specialisation in the degree obtained, thereby creating a real obstacle for return migration. In this manner, the study also described the dynamics hinted at by (Faggian & McCann, 2009c) with regard to the post-1992 universities being better oriented to local economies and thereby supporting the retention of graduates. These findings suggest that universities are not cathedrals in the desert but are well positioned to contribute to regional industries. However, more in-depth research is required to determine the precise mechanism that facilitates the alignment of the teaching mission to the regional industries. Paper C provides insight into this topic.

5.2.3 Paper C: Co-creation of localised capabilities between universities and nascent industries

In Paper C, the case study of Aalborg University highlights the role universities can play (via collaborative research efforts and graduates) on the creation of localised capabilities through university–industry feedback loops, thereby enabling industries to prosper in the region. Here, it could also be part of the explanation of the findings of Paper A: bottom-up dynamics through critical mass in industry are crucial to the success of these feedback loops.

Thus, this paper contributes to the university-industry interaction literature on the regional impact of universities (Charles, 2006; Uyarra, 2010) by offering a contextualised explanation of how these feedback loops can stimulate the development of specific industries and thereby realise a regional impact of universities. Although, in principle, this explanation is only applicable to a context like the one reviewed in the paper, studies conducted in other contexts might still be able to draw lessons from the findings presented in this paper. Emphasizing the importance of bottom-up dynamics, this paper advocates for focusing the development of new industries in relation to what is already present in the region, which is in line with the related diversification strategy discussed in the literature (Boschma, 2017). While this paper addresses feedback loops, Paper D takes a closer look at some of the dynamics related to university–industry research collaborations.

5.2.4 Paper D: The effect of university–industry collaborations on firm-level human capital

Paper D highlights how companies adjust their hiring strategies when collaborating with universities. The findings indicate that when collaborating with a university, firms adapt their hiring to focus more on graduates, particularly graduates from their university collaboration partner and are more likely to hire PhD graduates.

This could be part of what Scandura (2016) describes as increased investments in R&D and expansion of R&D departments following a university–industry collaboration. By attracting these graduates, firms are better positioned to overcome the barriers of culture and absorptive capacity that Bruneel et al. (2010) highlight as obstacles to successful university–industry knowledge transfer. The main contribution of this paper is its demonstration of the permanent transformative powers of university–industry collaboration; by altering hiring dynamics, university–industry collaborations have a significant long-term impact on the composition of a firm's workforce, which will have an impact in a time window that is beyond the time period of the collaboration with the university. In this time window, the acquired graduates might, as Drejer and Østergaard (2017) indicated, plant the seeds from which new university–industry collaboration might emerge. While this paper examines graduates as mechanisms to facilitate knowledge sharing in university–industry collaboration, Paper E investigates in greater detail how organisations exchange knowledge in the context of collaborative projects.

5.2.5 Paper E: Knowledge sharing in smart grid pilot projects

The findings of Paper E indicate that knowledge sharing is a multifaceted process. Knowledge sharing is identified to take place at four distinct levels: intra-organisational, intra-project, inter-project, and project-external, each of which have specific sublevels, mechanisms, and barriers. While at some of these levels, there are incentive structures to enable knowledge sharing—the more organisational boundaries that need to be crossed, the less likely it is that knowledge sharing will actually take place.

By uncovering the different levels and their dynamics, this paper contributes to the literature on knowledge sharing in collaborative projects. Interactions between intra- and inter-organisational knowledge sharing are observed, which has also been discussed in previous literature (e.g. Easterby-Smith et al. (2008)). In this, organisations appear to follow a transaction cost logic (Williamson, 1979), which leads them to aim to limit costs by sourcing knowledge at the lowest level possible (beginning at the intra-organisational level) and, when necessary, contacting consortium partners but seldom consulting other projects or external actors for knowledge. At most levels, personal networks facilitate knowledge flow. For example, individual employees use their connections to share knowledge at the intra-organisational level. At the intra-project level, the employees of consortium partners share their knowledge. Inter-project knowledge flow occurs when employees form connections between projects. Only in the case of project-external knowledge sharing are personal networks less dominant, and this appears much more about finding the appropriate distribution channels. While Paper E discusses the importance of personal networks for transferring knowledge between individuals, Paper F examines how these networks can play an important role in transferring the individuals in which the knowledge is embedded across organisational boundaries.

5.2.6 Paper F: Doctoral Graduates' Transition to Industry: Networks as a Mechanism?

Paper F studies how PhD graduates, and thereby the knowledge embedded in them, transition to industry. This transition might be part of the intensified recruitment of PhD graduates by companies after collaboration with a university, which is described in Paper D. The findings of Paper F indicate that personal networks play an important role in both finding a doctoral graduate's position in industry and adapting this position to the graduate's knowledge and skills.

Apart from their pre-existing connections from prior work experience, graduates also initiate new connections that lead to employment in industry. Contrary to Mangematin's (2000) observation that PhDs generally do not possess the requisite networks or experience to explore non-academic career options, the research suggests that PhD graduates not only have the requisite networks but also initiate the necessary connections and may prefer to rely on their personal networks.

5.3 General discussion

This thesis set out to answer the following main question: What is the role of university–industry research collaborations and graduate production in the impact of universities on regional industrial development?

The contribution of the individual papers described in the previous section jointly provide an answer to this question. This section assesses these contributions in relation to some of the discussion in the literature. It is crucial to take these discussions into account when interpreting the findings of the individual papers.

5.3.1 The independence and openness of universities

This thesis strongly argued for and provided evidence of some of the potentials of university–industry interaction for regional industrial development. Yet, the rise of the third mission of universities has been met with varying responses in the literature. While some scholars have studied all the different channels through which university knowledge could be used to realise economic impacts (Henderson et al., 1998; Mansfield & Lee, 1996), others raised concerns regarding how the development of this third mission could negatively affect the missions of research and teaching (D'Este & Perkmann, 2011). Nelson (2001, p. 19) emphasizes that throughout the discussion on third mission activities, *"universities should not forget or neglect that their comparative, or absolute, advantage in national innovation systems, lies in the arenas of open public science and training"*.

With regard to the research mission, concerns have been raised regarding how third mission activities could affect the goals of public research and the appropriation of research outputs (Giuliani & Arza, 2009). Traditionally, universities are more concerned with basic research, which might generate societal value in the long term. Yet, interactions with industry tend to be more applied in nature and can thereby constrain the basic research potential of universities and move them to perform more applied research (Behrens & Gray, 2001). Further, third mission activities, such as patenting and spin-offs, can limit the openness and dissemination of science by introducing commercial interests into the equation (Murray & Stern, 2007).

In the context of the third mission, the employability of university graduates has become a key measure to consider the relevance of the teaching mission of universities. This thesis assessed employability, particularly at the regional level, as being important for evaluating the regional impact of universities. Yet, several studies have raised concerns with regard to placing excessive emphasis on employability (Boden & Nedeva, 2010; Harvey, 2000; Moreau & Leathwood, 2006). Reducing the teaching mission to merely supplying to meet the needs of industry reduces the freedom of universities to set their own priorities regarding education. Equipping graduates with only the skills required by regional industry might reduce the possibility for graduates to introduce new insights and ways of thinking into industry. Further, the learning potential of degrees might be decreased by targeting them to a specific industry rather than equipping students with the ability to learn (Boden & Nedeva, 2010). Although these are valid concerns, the opposite situation—in which universities are disconnected as ivory towers from their surroundings—is not preferable either. There should be a balance between connecting the teaching mission to the demand of regional industry and providing universities autonomy in putting this connection into practice.

5.3.2 The efficiency of universities as a policy tool

This thesis argued that university–industry interactions are important for fostering regional industrial development. However, concerns were raised regarding the effectiveness of third mission activities for regional economic development. While Power and Malmberg (2008) acknowledge that universities can generate some knowledge spillovers, it is questioned whether allocating money to universities for this purpose is the best means of realising regional impact. This a valid concern, particularly if only multiplier effects are considered—public money could probably be better spent on other initiatives to realise regional economic development. However, the findings of this study do not necessarily call for the allocation of additional financial resources to universities, but they do emphasize the need to adjust how current resources are utilised without overturning the entire system. A few suggestions for policymakers are provided in subsection 5.5.

5.3.3 The regional and global character of universities

This thesis emphasises the regionalised impacts of universities. This is because most of the third mission channels tend to favour interactions on a smaller geographical distance. However, it must be emphasized that universities also do have impacts outside their regions. The case of Aalborg University (described in Paper A) indicated that, in the long term, the university developed into an educational provider at the national level. Additionally, it is also known from other studies that a large share of university graduates are educated for labour markets outside the region of the university (Faggian & McCann, 2009c). This has even become more important in recent years due to the growing internationalisation of university education (Adnett, 2010).

Further, the research networks in which universities participate are increasingly recognised by their international character as best visible through the internationalisation of the workforce, cross-border research collaborations, and international conferences (Glänzel et al., 1999; Katz & Hicks, 1997; Liberman & Wolf, 1997; Walker, 2015).

Although universities tend to have an international profile, most university–industry channels—particularly the research collaboration and graduate human capital channels—are characterised as regional, as argued in the first section of this synopsis. Therefore, although it is possible that these university–industry channels also play a role at the extra-regional level, their strong geographical concentration led this thesis to focus on the regionalised impact of universities.

5.3.4 Obstacles to university–industry interaction

The third mission requires universities to invest time in adjusting current activities and developing new ones. However, work pressure tends to be already high in academia, thereby limiting the opportunities for such adjustment and development. Further, uncertain career trajectories might push academics to conform to certain evaluation standards—like those regarding publication records in publish-or-perish paradigm—that are key for the progression of academic careers. Further, this thesis discussed the possibility that academics have a different mindset than industry actors and may lack the commercial drive that is required for the success of many third mission activities. Firms also need to adjust to be able to engage in third mission activities. First, they must achieve better absorptive capacity by employing more graduates, as discussed in Paper D. Second, industry actors must understand the academic incentives in place, like research interests, and ensure that interactions with industry also offer some value in for academics (Perkmann et al., 2013).

5.4 Recommendations for further research

While the papers included in this volume provided a comprehensive coverage of the main aspects that determine the role that university–industry interaction can play for regional industrial development, some questions arose or remained unanswered. These questions provide directions for further research into the role of university–industry interaction for regional industrial development.

5.4.1 Generalisability

The current literature on university–industry interactions has had a strong bias towards the US and European contexts. While recently a growing number of studies has covered different geographical contexts, more research must assess the extent to which the findings established in the literature for the developed world context can be applied to other contexts. As Paper C discusses in detail, it is crucial to understand the specific characteristics of a context before drawing conclusions. Replication studies in different countries, particularly those characterised by higher mobility or different stages of economic development, could help to clarify the extent to which the findings of this thesis are influenced by the specific Danish context. The accumulation of insights from these other contexts will help to strengthen the body of literature on the role of university–industry interaction for regional industrial development.

5.4.2 Unit of observation

Most papers have treated firms and universities as organisational entities. Yet, it is known that individual employees fulfil an important role in these interactions. Moreover, some of the discussed dynamics, such as the role of graduates that are hired in the context of university–industry collaboration, suggest that individual actors play an important role. However, data constraints have limited the ability of this thesis in terms of the extent to which insight can be provided in these dynamics. Given the importance of developing an understanding of these dynamics, it is recommended that further research be conducted, possibly exploring questionnaire or bibliometric data to provide insight into some of these dynamics. While questionnaires could directly ask respondents about these dynamics, bibliometric data could be used to assess whether university–industry co-publication relationships are maintained between organisations if one of the industry or academic authors decides to change organisations.

5.4.3 Qualitative insights into mechanisms

In addition to quantitative research, qualitative research is required to assess the precise functioning of some of the mechanisms described in this thesis. This will improve the understanding of which considerations play a role in universities' effort to adapt their educational mission to the industries present in the region in which the universities are located, thereby revealing whether these efforts are a response to policy or industry pressure or the result of societal awareness and conviction. Moreover, the literature could develop an understanding of the precise reasons underlying firms' decisions to recruit university graduates in the aftermath of a university–industry collaboration and the role that these graduates are supposed to fulfil.

5.4.4 Cultural development

Finally, it needs to be emphasized that industrial development, as a manifestation of economic development, does not occur in isolation from other developments taking place at the regional level. For example, employment is not the only factor affecting the regional retention of graduates and neglecting the development of an attractive living environment with sufficient (cultural) services is likely to diminish the impact of the employment factor. Investments in cultural services are deemed to be of importance for retain-ing highly educated individuals (Florida, 2005) and, therefore, they indirectly contribute to the creation of localised capabilities.

5.5 Policy implications

This thesis advances the understanding of the impact of universities on regional industrial development. The results reveal that universities can contribute to regional industrial development and highlighted the role of graduates and research collaboration in this process. The policy lessons to be derived from this thesis are particularly relevant to policymakers that are currently dealing with the potential establishment of greenfield universities or branch campuses. Moreover, other policymakers and university administrators can also benefit from the insights provided by this thesis by applying the lessons to existing educational institutions.

First, policymakers must carefully incorporate the regional context in their decisions on university policies. They must consider the extent to which their university is related to the industrial specialisation of their region. Failing to achieve relatedness is likely to reduce the potential contribution of universities to regional industrial development. The bottom-up dynamics of industry are crucial for enabling interactions with a university and thereby enabling a region to benefit from the presence of a university. Yet, solely relying on universities as drivers of regional development is hence not deemed to be feasible. In this regard, the thesis echoes the suggestion of smart specialisation policies (Asheim, 2014), according to which regions must build upon existing specialisations, while universities could also play a role in supporting some related industrial branching.

Second, a comprehensive approach must be adopted to ensure that policies related to university–industry collaborations consider the impact that could be realised through the graduate channel. Combining collaborations with the recruitment of graduates can increase the impact of collaboration. This also calls for a more integrated approach to be taken towards the evaluation of university activities. For example, hiring could be regarded as a positive outcome of third mission activities.

Third, policymakers must not expect miracles from university–industry interaction. Universities are, first and foremost, research and educational institutions. While policies can unlock the potential of universities to contribute to regional industrial development, simply establishing a university in a region will not help overcome all challenges or transform the industrial structure of the region.

Fourth, considering that knowledge transfer is far from an automatic process, policies must evaluate how this process could be supported. One possible means to support the process is by supporting the optimal utilization of the human capital of graduates by supporting the development of university–industry networks, as this can help PhD graduates to find employment and, thus, unlock the potential of human capital. In turn, the employment of these graduates in industry could then also fuel further university–industry interactions.

5.6 Final remarks

Many centuries after their initial conceptualisation, universities as institutions are still key actors for the functioning of societies. Over time, universities have constantly reinvented their missions and this is true for today as well. Currently, universities are under increasing social pressure to fulfil a variety of societal demands, including teaching and external engagement. While it might appear like the different missions may lead to internal competition for resources, this thesis emphasizes that this is not an equal sum game; the third mission activities of universities, like collaborations, can also increase the employment opportunities for their graduates and, potentially, benefit from the co-evolutionary dynamics that they fuel. By arguing for the regionalised impact of universities, this thesis aims to contribute to the academic discussion on this topic as well as to the potential of universities to play a role in boosting regional industrial development.

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Part II

Graduates and regional industrial development

Paper A

The impact of the establishment of a university in a peripheral region on the local labour market for graduates

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Abstract

The establishment of a university can be used as policy instrument to revitalise peripheral regions. Such newly established universities tend to experience rapid growth, but little is known about how this affects the labour market for graduates in these regions over time. A quantitative case study, employing individual-level microdata, analysed changes in the wage levels and mobility of graduates of Aalborg University, which was established in 1974 in the North Denmark region. The analysis shows that the establishment of Aalborg University contributed to the upgrading of the human capital in the region, fulfilling a demand in the labour market, as indicated by wage growth similar to that of the labour market in other regions and a growing percentage of local young people to stay in the region after graduation. Furthermore, the university increased its intake of students from outside the region, who then as graduates dispersed to other parts of the country, thereby serving to supply human capital at the national level. These insights add to our understanding of how a new university can play a role in the economic development of a peripheral region, while at the same time also having impact at the national level. Nevertheless, this instrument is not applicable to all regions in the same way, since local critical mass and regional embeddedness are required to enable a region to absorb a substantial number of graduates and benefit from the presence of the university.

Preface

The initial idea for this paper emerged during the writing of Paper C, which described a case study examining the impact of university–industry feedback loops within the ICT and biomedical sector in North Denmark. During this study, I began to wonder about the overall impact of the university on the regional economy. It was not long before I could study this topic in depth. During the RUNIN Summer School on the Role of Universities in Regional Development in June 2017, Paul Benneworth proposed a special issue in Region Studies Regional Science on the topic of the summer school. Consequently, I decided to develop my initial idea into a contribution for this special issue. In the year-and-a-half that followed, I was able to present the work in progress in a seminar during my secondment in autumn 2017 at the University of Lincoln, the Druid Academy Conference in Odense in January 2018, and the GEO-INNO conference in Barcelona in the same month. In February 2019, the paper was accepted for publication in Regional Studies Regional Science, becoming my first published paper in May 2019.

1 Introduction

Universities are increasingly expected to play an important role in regional development and innovation (Charles, 2006; Chatterton & Goddard, 2000). One of the reasons for this role is the growing requirement for knowledge in today's economy (Grant, 1996; Malmberg & Maskell, 2002). There is a dual role in this for universities; although universities can help businesses directly by collaborating, their main mission is the training of a highly skilled labour force, which enables organisations to process and utilise knowledge and thereby compete in the knowledge-based economy (Charles, 2006; Etzkowitz & Leydesdorff, 1995).

In the 20th century, the world experienced a rapid growth in the number of universities, and by the middle of the century most larger cities, often located in more central regions, hosted a university (Perkin, 2007). This development led to an increasing discrepancy in university attendance between peripheral and central regions, owing to commuting distances (Frenette, 2004; Looker & Andres, 2001). Furthermore, many of the young people who moved to other regions to pursue their studies did not return afterwards to their original home areas (Faggian & McCann, 2009; Groen, 2004).

Both these developments led to a thin labour market for graduates in peripheral regions and thus limited local companies' access to highly skilled labour (Tödtling & Trippl, 2005). Given the importance of this labour to compete in the knowledge-based economy, peripheral regions encountered difficulties in maintaining and developing industries. As a result, policymakers, often encouraged by local lobbying, established a university to remove this barrier to economic development. Increased university attendance naturally followed (Charles, 2016; Frenette, 2009), and over their first few decades most new universities grew rapidly. Ideally, these institutions' supply of human capital spur industrial upgrading and the growth of knowledge-intensive industries. However, having a university as a fast-growing supplier of graduates in the region is not sufficient, since it can also turn out to be a cathedral in the desert, where students obtain their degree before leaving because of a lack of industry demand for their skills. Furthermore, graduates who prefer to stay in the region can feel under pressure to take a job below their skill level, leading both to lower wages compared to their peers in other regions and reduced public returns on the investments in university education (McGuinness, 2006). Lower wages may in this case be a sign of a mismatch, in which employers in the region value the skills of the graduates less highly than employers in other regions.

Previous studies of graduate labour markets have offered some insights into the possible dynamics, but have failed to consider these dynamics in the context of the establishment of a university. To date, just a few studies have touched on this issue (Faggian & McCann, 2009; Saarivirta & Consoli, 2014), but data constraints have limited these studies to assessing mobility at just one point in time. Given the particular importance that university establishments have in revitalising peripheral regions, there is a need to explore these dynamics in more detail, by attempting to answer the following question:

> **What impact does the establishment of a university in a peripheral region have on the local labour market for graduates?**

This investigation takes the form of a quantitative case study on the establishment of Aalborg University in 1974 in the North Denmark region. The availability of micro-level data from all graduates in Denmark provides an opportunity to conduct a detailed and comprehensive analysis of graduate labour market dynamics following the establishment of the university. The analysis of these data shows that Aalborg University played a transformative role in the region by upgrading the human capital, fulfilling a labour market demand, as indicated by wage growth similar to that of the labour market in other regions and a growing percentage of local young people to stay in the region after graduation. Furthermore, the university increased its intake of students from outside the region, who then as graduates dispersed to other parts of the country, thereby serving to supply human capital at the national level. These insights add to our understanding of how a new university can contribute to the economic development of a peripheral region, while at the same time also having impact at the national level.

The next sections begin with a literature review, followed by methodology and presentation of the empirical results. The paper ends with a discussion and conclusion.

2 Universities and the graduate labour market

Although there is a variety of institutions that train people for the labour market, universities have the distinction of equipping their graduates with a unique set of capabilities focused on the incorporation and application of (relatively new) knowledge of a particular domain. Although the presence of these capabilities could also partly be explained by the selection effect of theoretically oriented young people being more likely to opt for a university education, nevertheless a university degree signals the presence of these capabilities. There has been a growing consensus that human capital plays an important role in economic development (Teixeira & Queirós, 2016), and that especially the university-taught capabilities of absorbing and processing knowledge are crucial to businesses' performance in the knowledge-based economy (Cohen & Levinthal, 1990).

This makes it crucial for firms to have access to a labour market in which they can acquire employees with these skills. However, there are substantial inter-regional differences in the supply side of the labour market for graduates, regions in the economic periphery tending to experience an undersupply. While these regions are often also situated in the geographical periphery, they are distinguished based on their lower wages (and wage growth), thinner labour markets and stronger reliance on traditional industries compared to the national average. The underdeveloped regional innovation systems in these regions often lack knowledge institutions such as a university for the training of graduates and provide a poorly developed labour market for graduates (Tödtling & Trippl, 2005). Furthermore, young people from these regions moving to core regions for their university education often do not return after graduation (Faggian, McCann, & Sheppard, 2007). This is partly because accumulated social capital in their new home region increases the opportunity costs for moving back to their former home region, but also partly because the underdeveloped labour market in the former home region is likely to reduce their current and future employment opportunities (King, Lulle, Conti, & Mueller, 2016).

The paucity of graduates in the labour market that peripheral regions without a university experience and the consequent limits to the ability of knowledge-intensive companies to hire the graduates they need is a process that has all the characteristics of a vicious circle, limiting the development of the local company base and making the region even less attractive for the next cohorts of graduates. Regional stakeholders, fearing that this will determine the long-term fate of their region, often start lobbying for the establishment of a university (campus) in their region. When a university is established, university attendance among local young people increases (Frenette, 2009) and the barrier for people at a later age to obtain a university degree is also lowered (Charles, 2016).

In the decades following the foundation of a university, student numbers tend to grow rapidly, leading to an increased number of graduates available on the regional labour market. However, although the wide availability of talent for local companies was one of the motives for establishing a university, the demand from the local labour market may not keep pace with the increasing supply of graduates. On the one hand, in most peripheral regions, firms were experiencing a shortage of highly skilled human capital before the establishment of the university (Tödtling & Trippl, 2005), which would suggest a good labour market position for the new graduates. On the other hand, the new educational institution lacks a track record and firms have little indication of the quality of the education it offers. Therefore, although the university provides many home-grown graduates, firms may still prefer to hire graduates from universities with a better reputation. However, in most cases, newly established universities build on preceding educational institutions in the region, which could give them some legitimacy from the start. Nevertheless, regions need to increase the local demand for graduates in order to reap the benefits of the fast-growing university. However, knowledge intensification and economic development of peripheral regions are gradual, long-term processes (Maskell & Malmberg, 1999).

The circumstances described above all influence either demand or supply in the graduate labour market. To bridge gaps between demand and supply, labour economists often turn to wage and labour mobility as instruments. However, intra-regional, inter-sectoral wage differences can be limited in countries with a strong presence of national bargaining agreements, such as Denmark (Due, Madsen, Jensen, & Petersen, 1994). On the other hand, where they encounter a lack of industry demand for graduate skills, graduates could decide to find employment in jobs that do not require such skills. By opting for a job for which they are overeducated, they are most likely to be paid less than their peers who are able to find employment that matches their skill level (McGuinness, 2006). Thus, intra-regional wage differences could even occur in labour markets controlled by collective bargaining agreements.

Mobility tends to be an even stronger indicator of labour market mismatches. Graduates are in general more mobile, and especially those who have been more mobile in the past are more likely to move again (Faggian & McCann, 2009). Therefore, when graduates enter a labour market in which there is insufficient demand for their skills, they may prefer to look for employment in other regions rather than to accept a position for which they are overqualified. Hereby, Low mobility among graduates signals an unmet demand, whereas graduates leaving the region indicates an oversupply of graduates. Although the departures of students for other regions does not necessarily qualify as a brain drain (Venhorst, Van Dijk, & Van Wissen, 2010), it is important that a significant proportion of them be retained for the local labour market to support the development of local industry and hence the local economy.

In a study among rural universities in Finland that were founded as part of new Finnish science and technology policies of the 1960s, Saarivirta and Consoli (2014) found that many of these universities lost considerable numbers of their graduates to more central regions close to the capital. By contrast, Faggian and McCann (2009) found low mobility among graduates of the post-1992 universities in the UK. However, neither of these studies took wages into account and both considered mobility at just one point in time.

3 Methodology

3.1 Empirical context

Aalborg University was established in 1974 in the North Denmark region, at the northern tip of continental Denmark. North Denmark is the smallest Danish region in terms of population, with around 590,000 inhabitants nowadays, of whom more than a third live in Aalborg (Statistics Denmark, n.d.-a). Before the establishment of the university, the region shared many of the typical characteristics of a peripheral region: a predominance of small, non-knowledge-intensive companies, a negative migration balance, relatively high unemployment numbers and a lower-educated workforce. Nevertheless, the region at that time was home to several technical higher education institutions that together formed the basis for the new university. This meant that the university did not need to start from scratch and could benefit from existing legitimacy in the region (Aalborg University, n.d.; Nilsson, 2006; Plenge, 2014).

The change to university status led to a sharp increase in student numbers, from 1,635 in 1974 to 6,410 in 1990. Nowadays, Aalborg University, having just over 20,000 students, is the fifth largest university in the country based on student numbers. The main campus in Aalborg has around 80 percent of the students, and there are smaller branch campuses in Copenhagen and Esbjerg. The university has five faculties (Humanities, Social Sciences, the Technical Faculty of IT and Design, Engineering and Science, and Medicine), of which the Faculty of Social Sciences, with 6,212 students, is the largest. However, the legacy of the preceding higher education institutions is still visible in the strong technical character of the university, and around 40 percent of the students are enrolled in one of the technical faculties (Aalborg University, 2018).

3.2 Data, variables and analyses

In order to study wage and mobility dynamics in the graduate labour market after the establishment of the university, register data from the Danish Integrated Database for Labour Market Research (IDA) are used. This database contains micro-level data for all individuals in Denmark, on an extensive set of variables, including wages, place of residence and educational history. Data for these variables are available from 1982 to 2006. University graduates are defined as individuals who completed a degree at one of the eight Danish universities, namely Aalborg University, Aarhus University, Copenhagen Business School, IT University of Copenhagen, Roskilde University, Technical University of Denmark, University of Copenhagen and the University of Southern Denmark. Insofar as the predecessors of these institutions can be classified as universities, their graduates are regarded as university graduates, while graduates from other Danish and foreign higher education institutions are not. Aalborg University graduates only recognise as such individuals who completed their degree at the Aalborg campus, since the Esbjerg and Copenhagen campuses are not geographically near to the Aalborg labour market region.

The wage analysis is based on an intra-regional comparison of the average hourly wage of all university graduates in a particular yearly cohort ten years after these graduates entered the labour market. The regions of interest are the four most urbanised labour market areas, proposed by Andersen (2002) and based on commuting patterns, which makes them more indicative for labour market behaviour than the administrative regions (see Figure A.1). The Copenhagen labour market region had a workforce of 1.1 million in 2006, significantly larger than the labour market regions of Aarhus (286,134), Odense (201,253) and Aalborg (159,757). Together, these regions represent nearly two-thirds of the total Danish workforce.

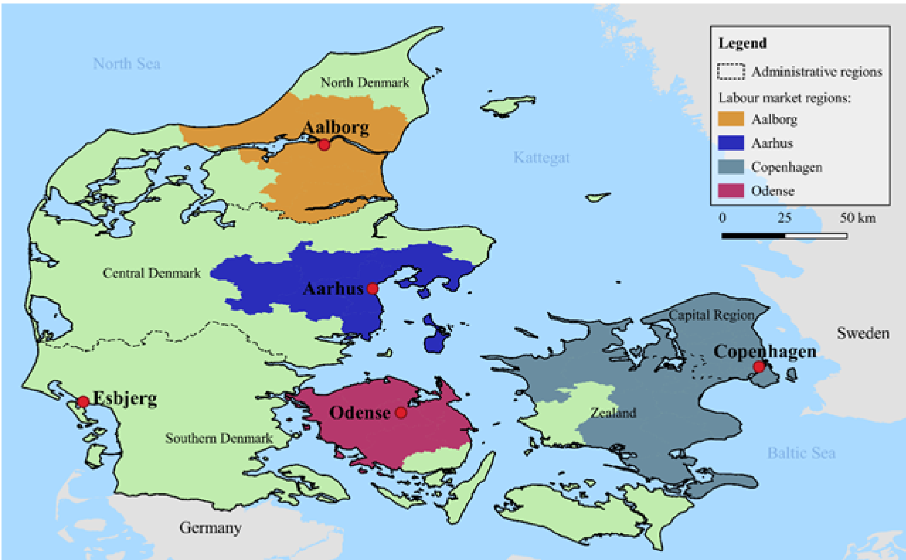

Figure A.1: The urbanised labour market regions in Denmark.

The period of ten years is chosen because employees tend to experience most of their wage growth within the first years of their employment (McCue, 1996), allowing a comparison at the end of the ten years that more clearly indicates wage development over their whole career. Furthermore, it allows wage data from 1982 to be used to assess the labour market position of university graduates from any Danish university who completed their degree in 1972. Any section of the population for which there is no valid estimate of the hourly wage is excluded from the wage analysis (Statistics Denmark, n.d.-b). The present mobility analysis distinguishes local graduates from incoming graduates, on the grounds that graduates who have moved before are more likely to move again (Faggian & McCann, 2009). Graduates are classed as local if they went to high school within an hour's travelling time of Aalborg University; all others are classed as incoming. Retention is assessed based on whether graduates continued to reside for five years after graduation within an hour's travelling time of Aalborg University.

4 Results

In 1982, just after the first cohorts of Aalborg University graduates entered the labour market, only 1.5 percent of the people in the workforce in the Aalborg labour market region had obtained a degree from any Danish university. The share was similar for the Odense labour market region, but the labour market regions of Aarhus and Copenhagen had a higher share of university graduates, at 2.3 percent and 2.8 percent, respectively.

The supply of graduates, both local and incoming, from Aalborg University increased rapidly after its establishment (see Figure A.2). Over the years, both groups have been about the same size and experienced similar growth. While the local graduates group developed from 42 graduates in 1977 to 673 in 2006, the incoming group developed in the same period from 75 to 742. These numbers demonstrate both rapid relative and absolute growth, and indicate that the establishment of the university has amounted to introducing a fast-growing supplier of graduates to the Aalborg labour market region.

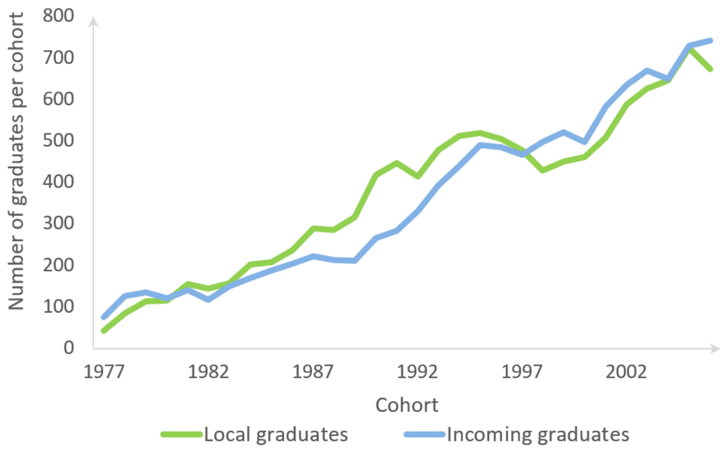

Figure A.2: Number of local and incoming Aalborg University graduates per cohort (compilation based on register data from Statistics Denmark).

The thin graduate labour market around Aalborg prior to the establishment of the university potentially weakened the bargaining position of graduates seeking employment or drove them to opt for jobs below their skill level. However, the wage development in Figure A.3 indicates that their hourly wage in 2006-adjusted Danish Kroner has risen in much the same way as that of graduates who have found employment in the other urbanised labour market regions. Only the graduates finding employment in the Copenhagen labour market region seem to have enjoyed a substantial wage premium compared to the other regions. These differences are partly due to the presence of multinationals in the capital, but partly also to the generally higher wage levels in metropolitan areas that are required to cover the increasing cost of living in such regions. The inter-regional similarities in wage growth, both for graduates and for the general workforce, are likely mainly due to the existence of national collective bargaining agreements, which offer some room for inter-regional differences but overall play a similar role in all regions in influencing wage growth. Thus, the limited wage difference indicates that graduates of Aalborg University are not compelled to apply for jobs for which they are overeducated.

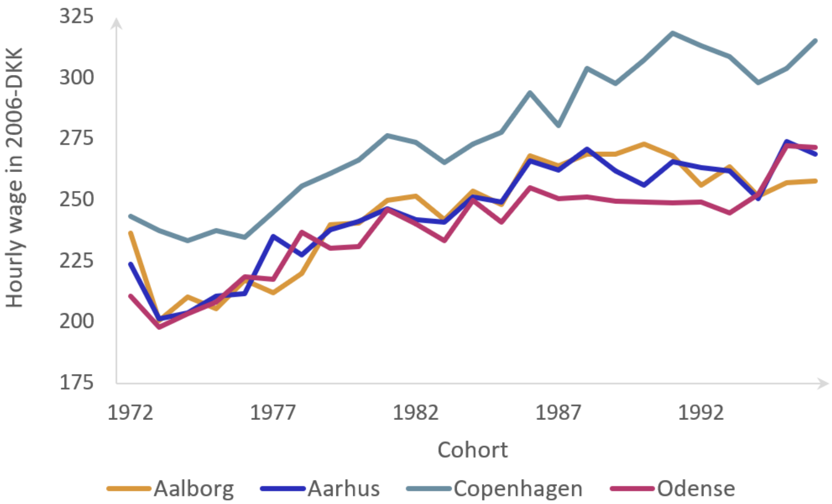

Figure A.3: Wage development ten years after graduation per cohort of university graduates (compilation based on register data from Statistics Denmark).

However, the similar rate of wage development could potentially also be the result of the tendency of graduates who are struggling to find employment to move to other regions. Insight into the mobility dynamics of the graduates of Aalborg University therefore provides complementary insight into the dynamics of the Aalborg labour market for graduates in general.

The mobility analysis focuses on the extent to which the Aalborg labour market can offer employment to Aalborg University graduates, by assessing the share of graduates that stayed in the near vicinity of Aalborg University after graduation. Figure A.4 displays the retention rates of Aalborg University graduates, again distinguishing local from incoming graduates. Both groups demonstrated high retention rates for the early cohorts, which could be due either to a strong unmet industry demand prior to the establishment of the university or to the university hiring its own graduates as staff to accommodate the very rapid growth of the early years. However, over time a more stable pattern emerged, with slowly increasing retention for the local graduates and a minor decline for the incoming graduates. Overall, in the context of rapidly growing graduate numbers, these stabilising retention rates indicate that graduates are increasingly being absorbed into the local labour market.

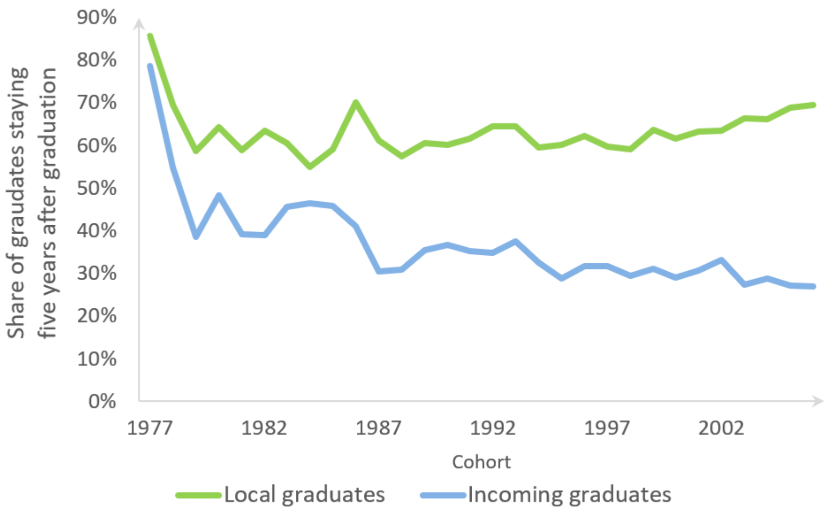

Figure A.4: Retention of local and incoming Aalborg University graduates per cohort (compilation based on register data from Statistics Denmark

Although Figure A.4 shows that the region around Aalborg absorbed more graduates over the years, it could be that other regions are also increasing their uptake of graduates, thereby perpetuating or widening the gap with the Aalborg labour market region. Figure A.5 accordingly displays the growth in the share of university graduates in the workforce of the urbanised labour market regions. While the Copenhagen labour market region experienced a 9.6 percentage point growth from 2.8 percent in 1982 to 12.4 percent in 2006 and the Aarhus labour market region grew 7.5 percentage points, starting from 2.3 percent in 1982 and reaching 9.8 percent in 2006, the Aalborg labour market region exhibited slightly smaller growth, of 7 percentage points, from 1.5 percent in 1982 to 8.5 percent in 2006. Nevertheless, considering relative growth rates, the share of graduates in the Aalborg labour market region more than quintupled, exhibiting significantly higher relative growth than the other labour market regions.

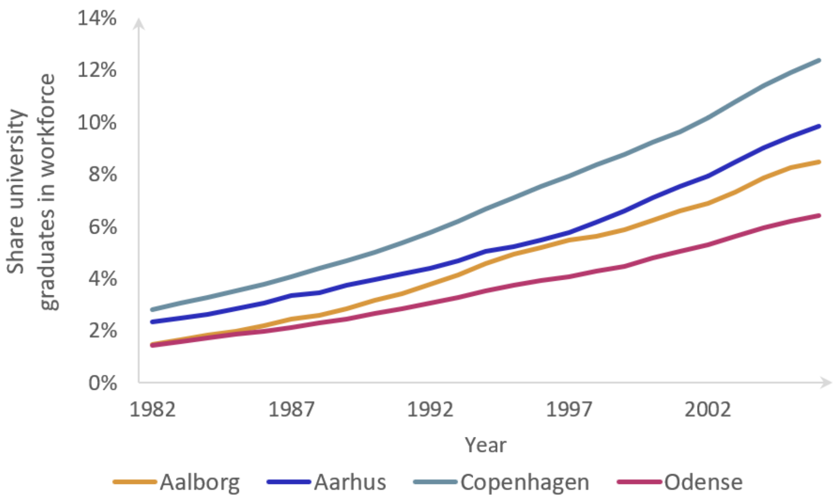

Figure A.5: Share of university graduates in the workforce per labour market region over time (compilation based on register data from Statistics Denmark)

5 Discussion

Although knowledge intensification and economic development of regions are gradual, long-term processes (Maskell & Malmberg, 1999), the case of Aalborg University has shown that the local demand for graduates can keep pace with the rapid development of a new established university in the region. Over the studied period, a substantial increase in the share of graduates in the Aalborg labour market region occurred, although slightly lagging behind the absolute growth in the Copenhagen and Aarhus labour market regions. This is in line with Berry and Glaeser (2005) who found that regions with higher human capital levels showed a larger subsequent absolute growth in the numbers of people with university degrees. However, the intra-regional absolute growth differences are small in the present case, and the Aalborg labour market region outperforms the other urbanised labour market regions in the relative growth in the share of university graduates in the workforce.

The limited number of studies of graduate mobility at new universities show a mixed picture. Faggian and McCann (2009) found limited mobility among the graduates of the post-1992 universities, which they explained by highlighting the stronger desire of these universities to cater to the local economies, since most of their funding originally came from the region. By contrast, Saarivirta and Consoli (2014), who conducted a study at five of the universities that were established as a result of the new national Finnish science and technology policies in the 1960s, found that regions could retain only a minority of their graduates in the region. These discrepancies could stem from differences in the orientation of the universities and the composition of the regional industry. Aalborg University and the post-1992 universities identify themselves as local actors, because their establishment was instigated by local stakeholders who were convinced that their region needed a university, and additionally because there was clearly substantial industry demand in the region. However, the universities studied by Saarivirta and Consoli (2014) were established in considerably smaller towns that lacked the critical mass of industry needed to make them an attractive place for new graduates to start their career. As Tödtling and Trippl (2005) argued, such differences call for tailor-made policies. In the specific case of universities, these kinds of initial differences can have long-term consequences, as shown in the universities of, among others, Tampere, Turku and Aalborg (Bruun, 2004; Guerrero & Evers, 2018; Kautonen et al., 2004). In a case study on the role of Aalborg University in regional development, Guerrero and Evers (2018) showed that the university co-evolved with the emerging ICT cluster in the region, both by conducting research in the area and by enhancing its degree offerings related to the sector. Admittedly, the university cannot take all credit for the emergence of the cluster, but it has undoubtedly played an important role in this process by supplying considerable numbers of graduates with skills relevant to the ICT industry.

Although this paper focuses on the impact in the region around Aalborg, the contribution of the university goes further than that. The present study shows that Aalborg University has continuously increased its intake of students from outside the region, of whom a growing majority have moved to other regions in Denmark after graduation. Thus, Aalborg University, originally intended as an instrument for regional development, has developed a role as an important supplier of graduates to other regions. The outward migration of graduates should not be regarded as a brain drain, but rather as part of a national task that a regional university can fulfil. Furthermore, the Aalborg labour market region can in the short run benefit from the multiplier effects generated by these students (Venhorst et al., 2010), and when industry demand spikes, the region can benefit from this partly untapped human capital potential.

Albeit this paper offers an insight into the Aalborg labour market region dynamics, it is primarily focused on the impact in the urbanised areas. For further studies, it would be interesting to see how these dynamics play out in the more rural areas. Nevertheless, this study, by encompassing two-thirds of the Danish workforce, gives a general picture of the dynamics and circumstances within Denmark.

Similarly, it is acknowledged that the establishment of Aalborg University may also affect the labour market dynamics of the other universities in Denmark. Before the establishment of Aalborg University, local young people had to move to other regions in order to obtain a degree, and a proportion of them returned afterwards. It is quite likely that significant numbers of such young people now opt for a degree at Aalborg University, whereas this might be less prevalent among students who were not planning to stay in the Aalborg region anyhow. This might mean that the share of returnees among young people who have moved to other cities to study has dropped after the establishment of Aalborg University, owing to the fact that 'potential returnees' are more likely to opt for studying in Aalborg. Further studies into these dynamics could provide more context to the findings of our study. Nevertheless, since the share of university graduates on the Aalborg labour market has shown a promising upward trend compared to other urbanised labour market regions, these effects will not cancel out the findings of this study.

6 Conclusion

The purpose of this paper was to look into the impact on the local labour market for graduates of the establishment of a university in a peripheral region in Denmark. The analysis showed that the establishment of Aalborg University effectively created a fast-growing supplier of graduates in the Aalborg labour market region. Although the wage analysis indicated some minor intra-regional differences in graduate wages, they are negligible when considering the cost of living. Furthermore, the retention rates of both local and incoming graduates have been stable over the last few decades, which implies, in a context of fast-rising graduate numbers, that graduates have increasingly been absorbed into the local labour market. Over time, this has resulted in larger numbers of graduates in the workforce of the Aalborg labour market, whose relative growth in terms of the proportion of graduates outpaces that of the other urbanised labour markets in Denmark. At the same time, Aalborg University has increased its intake of young people from outside the region and developed into a supplier of human capital at the national level. Thus, not only can the economy of a peripheral region adapt to and benefit from the establishment of a university, but also a positive impact can be felt at the national level.

Universities are therefore shown to be a useful instrument for providing the human capital needed for the development of local industry in the knowledge-based economy. Nevertheless, it must be stressed that this is not an instrument applicable to all regions, since local critical mass and regional embeddedness are required to make the region absorb a substantial number of graduates and benefit from the university. However, it is still unclear which threshold needs to be passed to make the establishment of a university a feasible policy instrument, while understanding that this is a highly relevant issue, since even smaller municipalities have now started lobbying for their own university.

Furthermore, this study looks at an aggregate level into both wage and mobility dynamics. Although this is considered to be the appropriate level for the present study, there are inevitable differences between study programmes. Therefore, further studies exploring how the growth of particular study programmes co-occurs with the development of the sectors in which most of their graduates find employment could contribute to the discussion about universities as a policy instrument.

This paper contributes to the limited literature on the impact on the labour market for graduates of the establishment of a university. The case study demonstrated that a newly established university had enabled regional transformation, and that, in line with Flyvbjerg (2006), acquiring context-dependent knowledge is crucial for improving our understanding of how university establishments can be used as a policy tool. Policy makers currently considering establishing a university to transform their region should make a point of understanding the characteristics of the region that are key in influencing the way it could benefit from the university.

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Paper B

The alignment of universities' teaching mission with the demands of regional industry

Gerwin Evers

The paper is currently under review.

The layout has been revised.

Abstract

The training of graduates is one of the means by which universities contribute to regional economic development. However, the effective utilisation of graduate human capital depends on the relatedness of the field of study to the industry in which it is employed. Arguing that several mechanisms yield this alignment on the regional level, this paper uses micro-level data to show how the educational specialisation of universities in the five largest urbanised labour market regions of Denmark is aligned to the local industrial specialisation. Policymakers need to value and promote this alignment, since its absence fuels a regional outflow of graduates.

Preface

The initial idea for this paper originated during the writing of Paper C, which described a case study examining the impact of the university–industry feedback loops taking place with the ICT and biomedical sector in North Denmark. The observed co-evolution of university activities and industry in the ICT sector led me to wonder whether this was a unique effect or whether it represented a more general pattern of university activities developing in relation to the regional economy. When I became aware of a relevant special issue call, I decided to investigate how the teaching mission of universities was related to the industries present in the region. The work-in-progress was presented in January 2020 at the GEO-INNO conference in Stavanger and is currently under review.

1 Introduction

The ways in which universities can contribute to regional economic development are widely discussed in the literature. By providing industries with knowledge through university–industry collaborations, new ventures via the creation of spin-offs and human capital via the training of graduates, universities play an important role in shaping the development of their regions (Charles, 2006). The extensive literature on these distinct mechanisms has provided insights into why firms collaborate (Santoro & Chakrabarti, 2001), how they collaborate (Bekkers & Bodas Freitas, 2008; Perkmann & Walsh, 2007) and how to evaluate the outcomes of these collaborations (Perkmann et al., 2011), as well as covering the processes by which spin-offs are created and how these contribute to the development of local industries (Pérez & Sánchez, 2003; Pirnay et al., 2003). Human capital, in turn, has been identified as a key asset for firms competing in today's knowledge-based economy (Berman et al., 1998; Crook et al., 2011), and university graduates acknowledged as carriers of the most knowledge-intensive human capital (OECD, 2016).

Although graduates trained by universities tend to exhibit more mobility than the general population, which indicates that regional labour markets for graduates are not closed systems (Faggian & McCann, 2009b), the general pattern is an uneven spatial distribution of graduates. These geographical disparities have been used as a starting point for explaining interregional differences in economic development (Faggian & McCann, 2009a). However, the industry specificity of human capital requires a more fine-grained understanding of its impact on regional development (Neal, 1995). The demand for human capital in a particular study field and thereby its impact on economic development will depend on the regional presence of industries related to this study field. For the optimal functioning of regional labour markets, the specific skills in the graduate population should match the specific skill demands from local industries. While the increased mobility in the graduate populations allows for some geographical redistribution to resolve potential mismatches, graduates still have a strong tendency to opt for employment in their region of study (Evers, 2019; Faggian & McCann, 2009b), possibly because of a preference to stay close to friends and relatives (Berck et al., 2016) or because their geographically focused professional network is an incentive to stay in that region (Huffman & Quigley, 2002). This makes local industries more attractive employers for university graduates, while industries at the same time need to overcome these same barriers when sourcing graduates from other regions. While metropolitan areas are deemed more attractive and firms in these regions are therefore better positioned to attract graduates from outside the region, lower mobility among graduates from universities in metropolitan areas means that in such areas too the local universities are the most important source of human capital for regional industries (Haapanen & Tervo, 2012).

Since industries are more reliant on graduates trained in their region, universities can deliver a significant economic contribution to the region by aligning their educational specialisation with regional industries. This paper argues that several mechanisms lead to the co-evolvement of the specificity of a university's human capital production with the regional industries in which its graduates find employment. Universities, either via proactive interaction with local industry or due to external policy pressure (Charles, 2016), are likely to align their teaching mission to the demands of industries in their region. Although the educational system is inevitably partly driven by students' demand for education, universities can influence the supply of graduates by determining which programmes and how many places to offer and by marketing specific study programmes. From the perspective of prospective students, joining a study program at a university in a region with strong industries connected with their field of study offers knowledge of and access to valuable student internship and employment opportunities. Employers from outside the region might also attach a higher value to a degree obtained in such a region. Local young people may even be more attracted to these programmes by offering them the possibility to contribute to one of the regional strongholds and increase their chances of finding employment in their home region.

Some studies have analysed how these dynamics can unfold in well-known industry clusters. Cases include the universities in the Boston area supporting the development of the biotechnology cluster (Breznitz & Anderson, 2005; Porter et al., 2005) and Stanford's role in the evolution of Silicon Valley (Adams, 2005; Saxenian, 1996). However, also smaller, less well-known examples of these dynamics have been reported, in which companies played an active part by supporting study programmes and urging universities to deliver the graduates they need (Ahoba-Sam et al., 2018). While these case studies have provided insights into the dynamics of this interdependency between the human capital provided by the university and the industry of the region, it is not known whether these are unique cases or whether they exemplify a more general pattern. Furthermore, arguing for the importance of these dynamics also indicates a need to understand the possible effects of their absence on the regional retention of graduates in case the local labour market has no demand for their skills.

This study draws on individual-level micro-data to provide quantitative insights into the extent to which the specific human capital provided by universities depends on the industries present in their locality. The study accomplishes this by studying how the graduate supply in study fields in the five largest urbanised labour market regions of Denmark has developed dependent on the local industries related to these study fields. The results indicate that universities adapt their educational offerings to local industry demand, universities are more likely to be among the first to offer new educations related to industries in the region, and that they have a larger proportion of their graduates in study fields related to these industries. However, universities' overspecialisation in study fields for which little industry demand is present fuels an outflow of graduates from the region. This first quantitative study into these dynamics contributes to the literature on the role of universities in economic development (Saxenian, 1996). The discussion also offers additional explanations for graduate mobility (Faggian & McCann, 2009b). The challenge for policymakers is to find ways to support co-evolutionary processes between graduate production and their industries of interest.

The paper is structured as follows. The next section presents a literature review, followed by the methodology and the empirical results. The paper ends with a discussion and conclusion.

2 Literature review

The success of local industries is the main driver of regional economic development. Prospering industries can provide both employment and tax revenue that can provide resources and essentials for investment in infrastructure and public services. However, in the current knowledge-based economy, industries increasingly depend for their success on utilisation of and hence access to human capital. Human capital, which consists among others of intellectual and social capital, is one of the key factors determining the productivity of individual employees and thereby firm-level productivity (Berman et al., 1998). Traditional studies of human capital differentiate human capital according to the level of education received, often focusing particularly on graduate human capital because of its presumed increased importance (OECD, 2016). However, the wide availability of graduate human capital is not necessarily sufficient to meet firms' demands, since human capital is highly industry-specific (Neal, 1995). The finding that graduates employed in a sector closely related to their education receive substantially higher wages than their peers working in unrelated sectors (Kinsler & Pavan, 2015) suggests that the value that firms can obtain from graduates depends on how closely their degrees are related to the sector in question. Therefore, firms with a stock of relevant graduate human capital are likely to outcompete firms that lack it (Crook et al., 2011). In this way, the development of industries, and thereby the regions that host them, depends on the availability of the relevant graduate human capital.

2.1 Universities aligning to local industrial demand for skills

While graduate supply and demand are not necessarily linked, several mechanisms appear to connect at the regional level the production of graduates to the specific demands of industries. The rise of the concept of the entrepreneurial university illustrates the trend towards a closer alignment between university and industry (Etzkowitz et al., 2000). Owing to reductions in the public funding of universities, industry has increased its importance as a funder of university research, allowing them to influence the strategic direction of such research (Gulbrandsen & Smeby, 2005). While these funding streams are primarily targeted at research, the motive for integrating teaching and research in the same institution is that spillovers from research may influence the direction of educational programmes. The knowledge obtained during collaborations may directly inform teaching (Holmén & Ljungberg, 2015), and contacts useful for arranging internships or job placements may be acquired (Lee, 2000). Collaborations have reportedly increased awareness among university staff of the knowledge and skills needed by industry (Azagra-Caro et al., 2006; van der Sijde, 2012), allowing them to adapt their study programmes accordingly. In some cases, teaching may be the prime aim of the collaboration when non-academic partners are directly involved in the teaching activities (DEA, 2014). Alternatively, the funds acquired in some collaborations, e.g. through licensing, may provide universities with more resources for their teaching activities (van der Sijde, 2012; Wang et al., 2016). Furthermore, when industry experiences an unmet demand for graduate labour, more resources could be allocated to these mechanisms in order to stimulate the training of relevant graduates.

At the same time, regional policymakers increasingly evaluate public universities based on their capacity to serve the demands of private labour markets (Charles, 2016; Mason et al., 2009; Sarrico et al., 2010). This requires that trained graduates fit into the local company base, ensuring that they stay in the region after graduation (Krabel & Flöther, 2014; Srinivas & Viljamaa, 2008; Venhorst et al., 2010).

Acting on this external pressure, universities can decide to create new study programmes, increase the number of places in existing programmes and invest in the marketing of programmes that cater to the needs of local industries. Furthermore, not only prospective students need to pick from the study programs available, even after choosing their major, their choice for a specialisation depends on what is made available and promoted by the universities.

Attractiveness of study fields related to regional industrial specialisation

Although there are university-side incentives aimed at catering to the regional industries, the education system is still to a large extent driven by demand from prospective students deciding what they want to study. Apart from their general interests in particular study fields, prospective students choosing a course of study attach importance to the availability of jobs, flexibility in jobs and career paths and job security over the course of a career (Beggs et al., 2008). Opting for study fields that have relevance to regional industry may offer them better future employment opportunities; equally, future employers' recognition of the value of the degree is taken into account when choosing a specialism and a university (Soutar & Turner, 2002). A degree obtained from a university in a region that is specialised in a particular sector may act as a quality signal for future employers. In this way, university educations catering to the local strongholds may also be in a better position to attract students from outside their region.

Further, the work and study experiences of relatives and acquaintances play an important role in students' decisions on what to study (Beggs et al., 2008), partly because these people are likely to be local with relevant information on the local labour market. While talk of attractive labour conditions and high demand for their skills may encourage students to pursue a particular career, reports of lay-offs or difficulties in finding jobs could have the opposite effect.

2.2 Interdependence between regional educational and industrial specialisation

The above-described push and pull factors between universities, students and industry tend to create an interdependence between the industrial specialisation of a region and its educational specialisation. As mentioned, labour market outcomes matter for the evaluation of universities and therefore the decision to offer degrees in a particular study field will depend on the presence of potential employers that are likely operate in an industry related to the study field. However, since universities exist in an environment of restricted resources, they need to make a prioritization regarding the study fields they offer. It is argued in this paper that the stronger the regional industrial demand for graduates from a particular study field, the more likely that the university will allocate some of its finite resources to offering degrees in that field. This leads to the first hypothesis:

> *Hypothesis 1: The stronger the regional industrial specialisation related to a study field, the higher the chance that the local university will offer that field*

While universities located in regions with a stronger industrial specialisation related to a particular study field are more likely to offer a degree in that field, it is likely that there are several universities offering degrees in that particular study field. However, the ones located in regions with a stronger industrial demand for graduates from that study field would be under greater pressure to not only offer the study field but would also do so earlier than universities in regions with a weaker relevant industrial demand. Therefore, the second hypothesis is:

> *Hypothesis 2: The stronger the regional industrial specialisation related to a study field, the earlier a university will offer that field*

Moreover, students may be more inclined to study a field that is strongly related to the industrial profile of the region and such students may thus represent a larger share of the total student population of the university. Therefore, the third hypothesis is:

> *Hypothesis 3: The stronger the regional industrial specialisation related to a study field, the higher the proportion of students studying in that field*

Where universities offer degrees that have little relation to the local industries, graduates are likely to struggle in finding employment. Even when there is related industrial specialisation to a study field, excessive educational specialisation of universities may still pose a disadvantage for graduates in the local labour market and are more likely to seek employment outside the region. The fourth hypothesis is:

> *Hypothesis 4: Educational overspecialisation will reduce the local retention of graduates*

3 Data and methods

3.1 Research Approach

Although qualitative evidence has accumulated on the relationships referred to in the hypotheses (Adams, 2005; Breznitz & Anderson, 2005; Guerrero & Evers, 2018; Porter et al., 2005; Saxenian, 1996), these relationships have not been evaluated quantitatively. One of the main reasons for this is that a quantitative investigation into the present topic requires detailed information on both employment and educational attainment. For this study, we employ micro-level data from the Integrated Database for Labour Market Research (IDA) of Statistics Denmark, which provide detailed information on the educational attainment, labour market position and geographical mobility of all individuals in Denmark over the period 1980–2007. However, another methodological challenge lies in capturing the complexity of the concepts and their dynamics. In this first attempt to provide a quantitative insight into these dynamics, we have aimed to be completely transparent about the variables and models employed. The study aims to test its hypotheses by analysing the quantitative data regarding graduates from all study fields trained by the universities in the five largest urbanised labour market regions of Denmark.

3.2 Empirical context

Figure B.1 shows the five labour market regions that are included in the study: Copenhagen, Aarhus, Odense, Aalborg and Esbjerg. These regions were proposed by Andersen (2002) and are based on commuting patterns, which makes them more indicative of labour market behaviour than the administrative regions. The Copenhagen region, with 2.4 million inhabitants in 2007, is the largest region, followed at a distance by Aarhus, with nearly 500,000, Odense with 379,000, Aalborg with 334,000 and Esbjerg with just over 209,000 inhabitants. Together the five regions represent close to 70% of the population of Denmark, and are responsible for the education of nearly all university students.

The Aalborg, Aarhus and Odense labour market regions are each home to one university, whereas the Copenhagen region has five universities (University of Copenhagen, Copenhagen Business School, Technical University

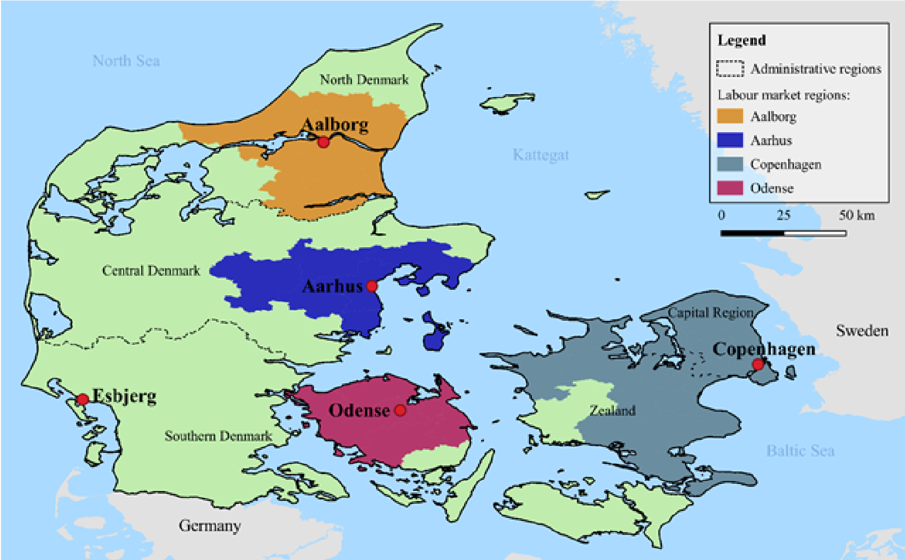

Figure B.1: The urbanised labour market regions in Denmark.

of Denmark, IT University of Denmark and Roskilde University) and two branch campuses (of Aalborg University and Aarhus University). Branch campuses of Aalborg University and the University of Southern Denmark are located in Esbjerg. The analysis is conducted on the labour market region level and for this the universities and branch campuses in Copenhagen and Esbjerg are aggregated to this level, meaning that graduates from the different institutions in these regions are grouped together as being part of one university. This approach slightly reduces the level of complexity in the analysis, but more importantly is taken because the presence of multiple universities in a region is likely to lead to the distribution of tasks; in the capital region, the Copenhagen Business School could focus on the training of accountants for the local financial institutions while neglecting the demands of the IT sector because that is perceived to be the domain of other institutions in the region, such as the IT University of Denmark.

At the beginning of our analysis period, all regions hosted at least one university and were training graduates. Copenhagen and Aarhus are the dominant regions, accounting in the 1980s for 87% of the graduates, before their share dropped to 79% in 2007 owing to the relatively fast growth in turning out graduates in Aalborg and Odense. Although Esbjerg also showed substantial relative growth, in numbers it remained small, accounting for just over 1% of all graduates.

3.3 Study fields

The micro-level data on study background yields information, on the individual level, on which degree was obtained, from which university in which year. The data on the degree obtained are not only very specific but also standardised across universities, resulting in the same education identifier assigned to individuals who completed similar degrees but at different universities. This education identifier consists of eight digits, of which the first two indicate the academic degree level, the next four the study field and the last two the specific area of focus within the study field (see Table B.1).

Table B.1: Educational classification system

Education identifier	**Degree level**	**Study field**	**Focus area within the study field**
60592524	Bachelor	Electrical Engineering and IT	Global business systems
60592525	Bachelor	Electrical Engineering and IT	Software engineering
60592526	Bachelor	Electrical Engineering and IT	Internet technologies - computer systems
60592527	Bachelor	Electrical Engineering and IT	Electronics and computer engineering
–15 more–	Bachelor	Electrical Engineering and IT	————–15 more————–
65592505	Master	Electrical Engineering and IT	Electronics IT
65592510	Master	Electrical Engineering and IT	Electronics
65592511	Master	Electrical Engineering and IT	Robotics
65592512	Master	Electrical Engineering and IT	Networking and distributed systems
–31 more–	Master	Electrical Engineering and IT	————–31 more————–

The introduction of the Bachelor and Master system has led to the creation of many different new educational codes that do not really represent changes in the teaching specialisation of universities. However, they are mere continuations of existing educations, and only the academic degree level has been changed. Furthermore, owing to the specificity of the last two digits, many educations, although similar in the industries to which they cater, are regarded as different specialisations. Therefore it was decided to conduct the analysis on the level of the study field (the four middle digits of the education code). The use of the classification was mostly consistent over time, necessitating only a few instances of manual reclassification or merging of existing classifications. Fields with fewer than 50 graduates over the period 1980–2007 were excluded from the analyses. On a few occasions, educations were classified into a generic field such as social sciences. However, this applied to only the graduates of a few social sciences degrees, while others were more precisely classified within study fields such as business administration and political sciences. Table B.2 shows an increasing number of study fields offered over time in Denmark as a whole, from 51 in 1980 to 64 in 2007. On the regional level, there was a noticeably larger growth in the number of fields offered. Whereas the universities in Copenhagen and Aarhus offered a broad coverage of the fields, the universities in the smaller regions could only offer a smaller range.

Table B.2: Number of study fields and graduates

	1980		*2007*	
Labour market regions	**Number of graduates**	**Number of study fields**	**Number of graduates**	**Number of study fields**
Denmark	6,630	51	24,226	64
Copenhagen	3,973	50	13,180	61
Aarhus	1,788	38	5,861	50
Odense	508	22	2,213	38
Aalborg	316	13	2,684	31
Esbjerg	45	4	259	13

Table B.3 categorises the study fields according to the number of regions offering them. In 2007, 12 degrees were offered by only a single university; this included specialist areas such as Music Therapy, Archaeology and Geophysics and Meteorology. Another 11 fields, including Civil Engineering and Economics, were offered in all regions.

Table B.3: Interregional overlap in study fields

Number of regions offering study field	*1980* Number of study fields	*2007* Number of study fields
One region	10	12
Two regions	19	11
Three regions	12	16
Four regions	7	14
Five regions	3	11

3.4 Regional industrial specialisation

Testing of the hypotheses requires an indicator for the regional industrial specialisation related to each study field. The available labour market data contain information on the employment sector for each employed individual. The Danish 111-industry grouping, which is based on the European NACE rev1 classification, divides economic activities into 111 distinct classes. Aggregating this data to the labour market region level shows how the workforce in each such region is distributed across the sectors. These figures are subsequently used to measure the regional industrial specialisation:

$$\text{Regional industrial specialisation} = \frac{N\ employees\ in\ region\ working\ in\ sector \big/ total\ regional\ workforce}{N\ employees\ in\ country\ working\ in\ sector \big/ total\ national\ workforce} \quad (1)$$

A coefficient larger than 1 indicates a regional specialisation of the particular sector. Table B.4 lists for the ten largest private sectors in Denmark the number of employees within the regional workforces, with the regional industrial specialisation in parentheses. The more urbanised regions of Copenhagen and Aarhus are clearly characterised by a stronger presence of business services and the recreation, culture and sport industry.

Table B.4: Top 10 private sectors by number of employees (specialisation)

Industry	**Copenhagen**	**Aarhus**	**Aalborg**	**Odense**	**Esbjerg**
All industries	1,195,016	258,807	167,124	184,548	107,151
Other business services	47,516(1.11)	11,548(1.24)	5,021(0.84)	7,023(1.06)	2,812(0.73)
Restaurants, etc.	31,856 (1.07)	6,579 (1.02)	4,445 (1.07)	4,427 (0.97)	2,540 (0.96)
Supermarkets, etc.	24,035 (0.97)	4,293 (0.80)	3,926 (1.13)	4,176 (1.09)	2,336 (1.05)
Recreation, culture and sport	30,025 (1.24)	5,738 (1.09)	2,762 (0.81)	3,467 (0.93)	1,615 (0.74)
Construction	22,653 (0.96)	3,786 (0.74)	3,405 (1.04)	3,987 (1.10)	2,255 (1.07)
Computer and related	31,341 (1.47)	6,039 (1.31)	3,087 (1.03)	1,884 (0.57)	670 (0.35)
Post and telecommunications	22,844 (1.08)	5,869 (1.28)	3,057 (1.03)	3,421 (1.05)	1,410 (0.74)
Financial institutions	24,524 (1.17)	4,621 (1.01)	2,853 (0.97)	2,329 (0.72)	1,434 (0.76)
Wholesale machinery, equipment and supplies	22,743 (1.10)	3,588 (0.80)	3,217 (1.11)	2,564 (0.80)	1,863 (1.00)
Industrial cleaning	19,846 (1.08)	3,549 (0.89)	2,432 (0.94)	2,661 (0.93)	1,690 (1.02)

Subsequently, data on both study background and the employment sector are used to show in which industries individuals from a particular study field find employment. Various fields have a strong link to a specific industry. Especially in the public sector, there are strong study field–sector connections, with most graduates in dentistry and medicine finding employment in the health sector, while language degrees tend to prepare students for a teaching career. Table B.5 lists the strongest study field–sector links found in the private sector, measured by the share of graduates in a particular study field who are employed in a given sector. Actuarial Science is the clearest example, preparing graduates for employment in the insurance and pension funding sector. Hence, Copenhagen and Aarhus, the two regions where this sector is most strongly represented, are the only two regions to offer degrees in this field.

Table B.5: Top 10 links between study field and (private) industry in 2007

Study field	**Industry**	**Graduates from study field employed in industry(share of total graduates in study field)**
Actuarial Science	Insurance and pension funding	167 (67%)
Theology and Religion	Activities of membership organizations, etc.	2,158 (62%)
Archaeology and Ancient Culture	Recreation, culture and sport	458 (51%)
Library and Information Science	Recreation, culture and sport	1,727 (46%)
Design - Innovation	Architectural and engineering activities and related technical consultancy	340 (43%)
Computer Science - IT	Computer and related	1,797 (42%)
Civil Engineering	Architectural and engineering activities and related technical consultancy	3,406 (33%)
Art History	Recreation, culture and sport	293 (32%)
Pharmacology and Drugs Science	Manufacture of pharmaceuticals and medicinal chemicals	1,009 (31%)
Geophysics and Meteorology	Research and development	60 (30%)

Since not all graduates from a particular study field find employment in the same industry, it is not possible to assess one-on-one relationships between the regional industrial specialisation and the study field specialisation of the universities in that region. Therefore, this study constructs the regional study field–industry relatedness variable for each field, in order to arrive at an average of the regional industrial specialisation weighted by the share of graduates from that field who find employment in each industry:

$$\begin{matrix} \textit{Regional study field}- \\ \textit{industry relatedness} \end{matrix} = \sum_{N \to 99} \textit{share field graduates employed in sectorN} * \textit{regional}\ \text{sectorN specialisation} + \ldots \quad (2)$$

Table B.6 provides a fictitious example of the relatedness of the study field of Electrical Engineering and IT with the industries present in fictitious region Y. A substantial share of the graduates in Electrical Engineering and IT find employment in the first three listed sectors. The first two of these industries happen to be strongly present in region Y (indicated by industrial specialisations of larger than 1), while the third is underrepresented. For every field, there are also always graduates that end up in sectors that are not related, such as IT graduates who end up in the restaurant industry. To correct for this, only sectors that employ at least 1% of the graduates in a particular field are used to calculate the weighted average. The resulting coefficient of 1.98

Table B.6: Industry of employment for Electrical Engineering and IT graduates (simplified fictitious example)

Industry	Share employed in industry at national level	Industrial specialisation in region Y	Weighted specialisation
Computer and related activities	40%	2	0.8
Manufacture of office machinery and computers	35%	3	1.05
Manufacture of radio, television and communication equipment and apparatus	24.5%	0.5	0.1225
~~*Restaurants, etc.*~~	~~0.5%~~	~~1.5~~	~~0.0015~~
Sub total	99.5%	n.a.	1.9725
Study field–industry relatedness for Electrical Engineering and IT in region Y	100%	n.a.	1.9824

indicates that there is a strong presence of industries in region Y that usually employ graduates in Electrical Engineering and IT. Thus, a coefficient greater than 1 indicates a regional industrial specialisation in sectors relevant to the particular study field.

It should be noted that the share of graduates from a particular study field employed in a given sector is calculated at the national level; thus, the 40% of Electrical Engineering and IT graduates employed in the computer and related activities industry in the above example is 40% at the national level. This includes all people who have obtained a degree in Electrical Engineering and IT from any university in Denmark, which provides a good indication of the relevance of a particular study field to a particular industry. Although taking this measure at the regional level would still give a good indication, it might lead to some bias, suggesting a relatedness between industries and educations driven by the particular industrial composition of the region. Creating, for example, an Actuarial Science degree in the Esbjerg region, a region with few employment opportunities in the insurance and pension funding sector, may push some of these graduates to find employment in other sectors in the region. While there is likely still to be a preference to go for related sectors, this might bias the found ties to reflect the industrial composition of the region. Measuring these study field–industry ties at the national level, assessing only the five largest urbanised labour market regions and acknowledging that graduates can also sometimes move to other regions in search of employment remove this bias.

3.5 Analysis

Four different models are constructed for the analysis of the hypotheses. Model 1 requires a dummy variable indicating, for each region and each study field, whether the local universities delivered graduates in that field. This dummy is used as the dependent variable in a logistic regression model, with the regional study field–industry relatedness as an independent variable. Regional dummies are added to control for the fact that larger regions are in general more likely to be offering a degree simply because of their sheer size. Based on Hypothesis 1, we would expect that a stronger regional presence of industries relevant to a study field, measured by the regional weighted relevant industrial specialisation, would increase the likelihood that local universities will offer degrees in this study field. An odds ratio larger than 1 for the independent variable regional study field–industry relatedness would confirm Hypothesis 1. Model 2 requires the construction of an ordinal variable indicating, for each study field, the chronological order in which regions started to deliver graduates in that field. Regions that never offered a degree in a particular field are not assigned a rank. The region that was the first to deliver graduates in a particular degree is assigned rank 1, the second being rank 2 and so on. Duplicate ranks for a particular field can occur if universities started offering a particular study field in the same year. This order is used as the dependent variable in an ordinal logistic regression model, with regional study field–industry relatedness as the independent variable. An odds ratio smaller than 1 would indicate that stronger regional study field–industry relatedness would make it more likely for a region to start offering degrees in a particular field earlier, which would be in line with Hypothesis 2. Regional dummies are added because some regions, such as Aalborg and Esbjerg, were relatively late in acquiring a university, making it harder for them to be among the first universities to offer a degree in a particular field. Study fields that regions started to offer before the 1980s are not included in the analysis, since there are no data on the regional study field–industry relatedness from that period.

Model 3 requires the construction of the regional study field specialisation variable:

$$\text{Regional study field specialisation} = \frac{{}^{N\ graduates\ in\ region\ in\ study\ field}\!/_{total\ N\ graduates\ in\ region}}{{}^{N\ graduates\ in\ country\ in\ study\ field}\!/_{total\ N\ graduates\ in\ country}} \quad (3)$$

Table B.7 lists the ten largest study fields in the absolute number of graduates in 2007, with the regional field specialisation in parentheses. The reported study field specialisation of 1.10 in Business Administration indicates that the proportion of graduates in this field was 10% above the national average. In this way, a coefficient larger than 1 indicates an above-average

Table B.7: Top 10 study fields by number of graduates in 2007 (specialisation)

	Copenhagen	**Aarhus**	**Aalborg**	**Odense**	**Esbjerg**
All study fields	11,955	5,269	2,547	2,095	287
Business Administration	2,469 (1.10)	904 (0.90)	439 (0.97)	290 (0.77)	35 (0.71)
Law	925 (1.16)	497 (1.40)	0	48 (0.36)	0
Engineering	846 (1.06)	77 (0.22)	439 (2.71)	20 (0.15)	81 (4.66)
Medicine	997 (1.32)	252 (0.75)	0	137 (1.08)	0
Business Communication and Languages	433 (0.74)	413 (1.60)	71 (0.60)	145 (1.48)	8 (0.63)
Journalism and Media	270 (0.60)	203 (1.02)	147 (1.61)	202 (2.69)	0
Social Sciences	643 (1.45)	21 (0.11)	142 (1.57)	10 (0.13)	0
Psychology	401 (0.95)	262 (1.40)	109 (1.27)	0	0
Political Sciences	251 (0.63)	324 (1.87)	14 (0.18)	129 (1.97)	0
Electrical Engineering and IT	230 (0.67)	111 (0.73)	161 (2.31)	112 (1.95)	14 (1.88)

proportion of graduates in a field for the universities in the region.

Especially in the smaller regions, specialisation is required, leading to a focus on certain disciplines and no resources allocated to other fields. Some of these specialisations are implemented top-down, such as the appointment of three universities for the training of medical doctors and controlling the admission of students into these programmes. Preventing geographical disparities in access to medical care has been a topic of debate, which led to the opening of a medical faculty in Aalborg in 2010, ensuring a more or less countrywide offering of medical degrees. Other specialisations are more market-driven, such as Electrical Engineering and IT in Aalborg, Odense and Esbjerg, which could be related to the stronger presence of manufacturing industries in these regions. Model 3 only considers study field specialisation for regions that have graduates in that particular field. The logarithm of the regional study field specialisation is the dependent variable in the linear regression model. The regional study field–industry relatedness is used as independent variable. A positive coefficient would indicate that a stronger regional presence of industries relevant to a study field would lead to an increased specialisation of the local universities in that field, and thereby confirm Hypothesis 3. Regional dummies are added because smaller regions tend to have a stronger specialisation and a smaller potential to diversify their educational offerings.

Model 4 requires the construction of an overspecialisation-ratio for each study field in each region:

$$\text{Regional study field overspecialisation ratio} = \frac{Regional\ study\ field\ specialisation}{Regional\ study\ field - industry\ relatedness} \quad (4)$$

If a region has a strong study field specialisation in, for example, Biotechnology, but the industry demand is low, indicated by a low regional study field–industry relatedness for biotechnology, the overspecialisation ratio will be high. The dependent variable in the linear regression model will be the share of graduates in a particular field trained in a particular labour market region who are still residing in that region five years after graduation. The five-year time lag is chosen to make sure that graduates have made a more or less long-term decision on how and where to pursue their careers. The regional study field overspecialisation ratio is the independent variable. Regional dummies are added to control for a general tendency of graduates to move to more urbanised regions, which in Denmark means an outflow from all regions to Copenhagen. A control for whether the graduates are studying in their home region is also included, since graduates who have not previously moved are more likely to stay in their region (Faggian & McCann, 2009b).

3.6 Empirical considerations

The results for models 1, 2, and 4 are based on the 2007 data. The data for model 3 were selected in the year the region delivered the first graduates in a particular study field, to accommodate the fact that the regional study field–industry relatedness can change over time. Several robustness checks were made by changing the years, and, apart from a few occasions when results became insignificant, they were consistent over time. Running separate models for each region yielded similar results, but sometimes, especially for the smaller region of Esbjerg, these tended to be less significant or insignificant. For the models included, the applicable assumptions were checked. In general, the estimates in models 2, 3 and 4 tended to be conservative, since regions that did not offer degrees in the field in question were excluded. The findings of this paper are unlikely to be invalidated by reverse causality, since the creation of a particular degree course will not have the capacity to transform the workforce in the short term: industrial transformation is a rather long-term process (Maskell & Malmberg, 1999).

4 Results

Some of the descriptors presented in the previous section, such as the offering of degrees in Actuarial Science happens only in the regions with the strongest insurance and pension funding sector, already indicated some relatedness between the educational offerings of universities and the industries present in the region. The aim of this section is to assess whether this is a more general pattern. Table B.8 displays the results of the regression models used

Table B.8: Regression models

	Model 1	**Model 2**	**Model 3**	**Model 4**
	Logistic regression on the likelihood of a university offering a particular degree (odds ratios)	Ordinal logistic regression on the chronological order in which universities started offering a particular degree (odds ratios)	OLS regression on the log (regional study field specialisation)	OLS regression on graduate retention rate five years after graduation
Regional study field–industry relatedness	13.60*	0.004**	1.29*	0.11
Overspecialisation ratio	n.a.	n.a.	n.a.	-0.02**
Share of local graduates	n.a.	n.a.	n.a.	0.32***
Labour market region dummies (Copenhagen reference)				
Aarhus	0.19*	71.455***	0.00	-0.33***
Odense	0.12**	14.905*	0.54**	-0.33***
Aalborg	0.09***	46.054***	0.55**	-0.40*
Esbjerg	0.03***	200.043***	1.57***	-0.20***
*Note: Statistical significance: *=0.05, **=0.01, ***=0.000*				

to validate the hypotheses.

The first two models report the odds ratio. The significant odds ratio of 13.6 on the top row of model 1 indicates that an increase of 1 in the regional study field–industry relatedness makes it 13.6 times more likely that a region offers the particular study field. In this way, the large significant odds ratio for regional study field–industry relatedness indicates that universities in regions with a strong industrial specialisation related to a study field are more likely to offer a degree in that particular field. Based on this, we can confirm Hypothesis 1. The fact that all regional dummies are smaller than 1 indicates that these regions are less likely to offer the degree compared to the reference category of Copenhagen.

Model 2 assesses the order in which the regions started offering a particular degree. A significant odds ratio smaller than 1 for regional study field–industry relatedness indicates that universities in regions with a strong industrial specialisation related to a study field are more likely to be among the first to train graduates in that field. Based on this, we can confirm Hypothesis 2. The regional dummies larger than 1 reflects that Copenhagen was the first region to train graduates in many fields. This is not surprising since this region is the largest and is home to the most universities.

Model 3 assesses the factors explaining the regional study field specialisation. The positive significant coefficient for regional study field–industry relatedness indicates that universities in regions with a stronger industrial specialisation related to a particular field are more likely to have a larger share of their graduates in that field. This confirms Hypothesis 3. The positive regional dummies for the smaller regions indicate that these regions are offering fewer study fields, resulting in a larger share of their graduates in the fields that they do offer.

Model 4 assesses the share of graduates of each study field that stay in the region of their university five years after graduation. The positive coefficient for regional study field–industry relatedness indicates that graduates are probably more likely to stay in their study region when there is a stronger industrial specialisation related to the study field, but the effect is not significant. However, the significant negative coefficient for the overspecialisation ratio indicates that, in cases where study field specialisation is not met by industrial specialisation, graduates are more likely to move away. This confirms Hypothesis 4. The negative regional dummies reflect the general tendency of graduates to move to Copenhagen.

5 Discussion

Albeit universities can undoubtedly deliver an important contribution to the economy of their region by providing high-level human capital to industry, the sector specificity of human capital demands that industry's needs be incorporated into the educational profile of universities. The quantitative analysis showed that universities in regions with a stronger industrial specialisation related to a study field are more likely to offer a degree in that field, are more likely to be among the first universities to offer such a degree and have a larger share of their graduates in that field. These findings suggest that universities do to some extent align their teaching mission to the industrial profile of their region, thereby helping graduates to find employment in the region. Furthermore, in line with the findings of Drejer and Østergaard (2017), this kind of alignment also sows the seeds for later university–industry collaborations by facilitating geographical, social and sectoral proximity between academic and industrial actors.

Relatedness between industrial specialisation and educational specialisation is not just a help to industries, but is also a necessity for regions that hope to reap the benefits from their university. The analysis of graduate retention showed that, where educational specialisation is not met by related industrial specialisation, graduates are more likely to move away from the region. Thus, a region that desires to use the university as a policy instrument for economic development and for the retention of local young people may fail to succeed on both counts. To some extent, regional educational overspecialisation is inevitable, owing to the economies of scale that are required to be able to offer degrees in niche subjects, but these educations could still be located in regions with the strongest industrial demand for them.

While all regions evinced a strong relationship between educational and relevant industrial specialisation, the relationship seemed to be stronger in less urbanised regions. This could be explained by the greater attractiveness of metropolitan areas to graduates (Haapanen & Tervo, 2012), giving industries in Copenhagen, and to some extent Aarhus, the freedom to recruit people from outside the region. By the same token, few graduates from Copenhagen can be convinced to move to Esbjerg. Therefore, universities and policymakers in peripheral regions should place ensuring relatedness between educational and industrial specialisation higher on their agenda.

While pressure is put on universities to connect to industry, policy and student demands, this study does not imply a one-way passive relationship in which a university conforms to the wishes of industry. University can by delivering graduates, have an important role in enabling the industries to develop. Moving beyond the world-famous to another case of this common phenomenon is the emergence of the wireless communication cluster around Aalborg in the 1970s and 1980s. Directly after the foundation of the university, it started catering to an industry that was already present in the region by creating departments in Electrical Engineering, offering new degrees and becoming the institution that trained the large majority of university graduates employed in the sector. This, together with the opening of research centres related to the wireless communication industry and the role played in the opening of a science park catering to start-ups in the sector, would eventually help the industry boom (Guerrero & Evers, 2018; Østergaard & Park, 2015). Yet, these university–industry interactions are not something from the past only, as an example from the University of Southern Denmark in Odense shows. By offering nearly 20 degrees related to the robotics industry, delivered by departments supported by the same industry, while also conducting related research, the University of Southern Denmark has played an important role in the development of the robotics cluster in Odense (Odense Robotics, 2020; University of Southern Denmark, 2019).

6 Conclusion

The findings of this study indicate that the teaching mission of universities tends to be closely aligned with the industries present in their region. Universities in regions with a stronger industrial specialisation related to a study field are more likely to offer a degree in that field, are more likely to be among the first universities to offer such a degree and have a larger share of their graduates in that field. Whereas several previous studies have discussed the existence of these dynamics in case studies (Saxenian, 1996), this study has made a first attempt at a quantitative investigation of these dynamics. The study also adds to the literature on graduate mobility. The fact that graduates move away from peripheral regions to study elsewhere and never return (Faggian et al., 2007) is often blamed on the underdeveloped character of these regions or the social capital developed during the study period that prevents moving back home (Berck et al., 2016; Huffman & Quigley, 2002). An alternative and additional explanation arising from the findings of the present study is that the region to which the individual moved to study may have an above-average industrial specialisation for the degree obtained, creating a real challenge to return migration. Furthermore, intraregional and interregional differences observed in the mobility of graduates could potentially be explained by differences in the regional educational overspecialisation.

The findings suggest that universities are thus not cathedrals in the desert, but are well positioned to contribute to regional industries. Our findings indicate that investing in a regional university can be part of regional economic development policy, but that alignment with the regional industries is key if these investments are to generate social and economic returns.

This study did not aim to explore the dynamics behind our models, nor the possible direction of influence. Case studies such as those carried out by Guerrero and Evers (2018) and Ahoba-Sam et al. (2018) have already provided insight into some of the dynamics that support the alignment. For further studies it would be interesting to incorporate the time dimension, in an effort to better understand the direction of causality. Does the university take the initiative and fuel the growth, or will industries set the process in motion by creating a demand that the university resolves to meet? While this study adopted a detailed micro-perspective by studying the dynamics at the level of field of study, answering these questions may require an even more granular approach that zooms in on the different specialisations present within study fields. Universities may start to offer specific degrees that are custom-made for just one industry. In the course of such developments, empirical challenges will arise, especially when considering degrees with only few graduates. Another possible extension of this study would be to include the university colleges in the analysis: there may be some overlap in labour markets between graduates from these institutions and university graduates, which could also possibly lead to a division of responsibilities, as observed in regions with multiple university institutions.

Concerning generalisability, it would be worth considering whether the dynamics discovered are specific to the Danish or Nordic context or whether this also applies in other countries, such as the UK, where graduates tend to be more mobile, neutralising the effect of educational overspecialisation. Nevertheless, in these contexts, peripheral regions may still need to come up with a way to supply their local industries with the necessary labour. The findings of the present study shed new light on universities not only as actors in global knowledge networks but also as rather locally rooted actors, catering to the industries of their region and thereby contributing positively to the economic fate of the region.

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Part III

Collaborative research and regional industrial development

Paper C

Co-creation of localised capabilities between universities and nascent industries

The case of Aalborg University and the North Denmark region

David Fernández Guerrero and Gerwin Evers

The paper has been accepted for publication in a book on the
Role of Universities in Regional Development and Innovation

The layout has been revised.

Abstract

This paper focuses on two cases of interaction between Aalborg University and science-based industries that have appeared in the region of North Denmark in the last decades: the ICT and bio-medical industries. These two cases provide a unique opportunity to study how localised capabilities developed through university-industry interaction: while both of them are science-based industries with tight linkages with the university, the outcome of the exchanges with the higher education institution has differed. Insight into these cases is provided by the combination of qualitative methods making use of secondary sources and interviews, and quantitative methods relying on micro and macro-level data from Statistics Denmark. The results indicate that the feedback loops between university and industry seem to have stimulated the development of localised capabilities favouring the competitiveness, and success, of the ICT industry. However, the university actions supporting the development of the biomedical industry do not seem to have been followed by growing industrial development. The key difference in these development processes is related to the size of these industries at the beginning of the relationship with AAU: The ICT industry was large enough to tap into the activities developed by AAU and fuel feedback loops, while the biomedical industry lacked the size to start these dynamics.

Preface

During the first training week of the RUNIN project, the idea was launched to write a joint book on the role played by the universities involved in the project in their regional economies. Adopting a historical perspective, David Fernández Guerrero and I studied the role of Aalborg University in the regional economy, focusing on its role in the development of the ICT and biomedical sector. While the former sector achieved success, the latter did not. Hence, covering both these cases provided insight into which factors are important for successful interaction between a university and a regional industry. The work was presented in a seminar at Aalborg University as well as at the Regional Innovation Policies conference in Santiago de Compostela in October 2017. The current version of the paper was accepted for publication in the joint RUNIN book on the Role of Universities in Regional Development and Innovation.

1 Introduction

Over the years, there has been a growing consensus about the role universities can play in stimulating the development of regional industries through the provision of graduates and the creation and transfer of knowledge (Charles, 2006; Drucker & Goldstein, 2007; Marques, 2017). We argue that universities with these activities can support the development of localised capabilities, which are regional characteristics that are difficult to replicate in other locations, supporting regional industries' sustained competitiveness (Maskell et al., 1998). Localised capabilities result from feedback loops: this implies that an actor modifies its strategies in response to what other actors do within the same region and that the interactions between them lead to the co-creation of localised capabilities(Maskell et al., 1998). In this paper, we contend that this line of reasoning also applies to the role of universities in stimulating regional industrial development: universities can support the creation of localised capabilities in their home regions with a wide range of activities, yet this is the result of feedback loops between university actions and industry developments. The intensity of university-industry feedback loops will influence the extent to which localised capabilities are formed.

Replicating the success of cases like Stanford that played an important role in the development of Silicon Valley or the Boston area universities' involvement in the emergence of biotech cluster in the region, has been a widely debated issue in policy circles; however, attempts at replicating such localised capabilities have been criticised for not taking enough into account the importance of local actors and context in the process (Maskell et al., 1998; Palazuelos, 2005). Industrial development policies in other regions could benefit from a deeper understanding of the interplay between the processes that facilitate the formation of localised capabilities. To examine how regions can develop localised capabilities in such industries, this paper analyses how localised capabilities are co-created between universities and nascent, science-based industries at the regional level. The focus is on the feedback loops that lead to, and result from university activities such as the creation and commercialization of knowledge, training of students and the application of existing know-how in collaboration with external partners (Drucker & Goldstein, 2007). This enquiry is guided by the following question:

> **How are localised capabilities co-created between universities and nascent industries at the regional level?**

The paper develops a double case study of the interaction in the North Denmark region between Aalborg University (henceforth AAU) and the ICT industry since the establishment of the university in 1974, and the interaction with the biomedical industry since the early 2000s. The North Denmark region, located in the northern tip of continental Denmark, provides an interesting setting for studying how university-industry interaction can stimulate the co-creation of localised capabilities. The focus on ICT and biomedical industries represent a shift from a region which was specialised in traditional industries such as construction and shipbuilding, to a more knowledge-intensive industry structure (Nilsson, 2006a; Pedersen, 2005). Also, the science-based nature of these industries suggests a greater reliance on universities' research (Pavitt, 1984), and thereby a greater likelihood that university-industry feedback loops will take place.

These industries tapped, since their early days into the educational, research and entrepreneurial activity of AAU in order to develop innovative capabilities that could support their growth. The university, in turn, has invested increasingly in activities that could support these industries. However, the outcome of university-industry interaction has differed between the two industries: While the workforce of the ICT industry has enjoyed considerable growth until the early 2000s, the biomedical industry has expanded to a much lesser extent. Therefore, the difference in outcomes provides an excellent opportunity for investigating how localised capabilities are co-created.

We suggest that the feedback loops between a university and a nascent industry at the regional level are key to the creation of localised capabilities benefiting the competitiveness of the nascent industry. However, we also suggest that the size of the nascent industry (measured by the number of jobs and companies) during university-industry interaction will also influence the extent to which these feedback loops lead to the co-creation of localised capabilities. Industries can tap into the educational, research and entrepreneurial activities of a university in order to develop innovative capabilities. The larger the industry, the more industry actors, the greater the possibilities for university-industry interaction, resulting in the university dedicating more resources to activities that will contribute to the development of localised capabilities relevant to the industry.

The cases we analyse in this paper take place in a specific setting. What we propose in this paper is a contextualised explanation (Tsang, 2013) of the processes that have facilitated the formation of localised capabilities between a specific university, AAU, and two industries (the ICT and biomedical industry) in the context of a particular region, that of North Denmark. Hence context might play a different role, in other regions, and transferability of the findings should not be presumed (Welch et al., 2011). Nevertheless, the findings from this paper could be complemented with other case studies in order to identify empirical regularities, and potentially propose new theory (Tsang, 2013).

2 Universities and localised capabilities

The concept of localised capabilities becomes fundamental when studying how university-industry interaction can reinforce the competitiveness of nascent industries at the regional level. Maskell et al. (1998, p. 11) define localised capabilities as geographically located assets increasing *"the ability of firms to create, acquire, accumulate, and utilise knowledge a little faster than their cost-wise more favourably located competitors"*. Localised capabilities include the structures built in a region, formal and informal institutions regulating business behaviour, and the knowledge and skills created by the regional public or private actors. Their distinctive, (quasi)non-replicable nature offers an advantage to regional firms. Competitors in other regions might try to replicate these conditions, but this might be difficult, in particular, if these assets are tacit (such as in the case of informal institutions) or complementary.

These localised capabilities result from the feedback loops between the economic agents populating the region. That is, how each actor reacts to what other actors have done, as is happening within clusters (Maskell et al., 1998). The region where one or few businesses settle might provide no advantage to these firms at the beginning. Nevertheless, the spin-offs emerging from these pioneers might prefer to locate nearby, in order to maximise the use of the industry-specific qualifications they already possess or to benefit from a regional network of social contacts. Over time, this process might generate a varied set of unique, localised capabilities. Multinational corporations (MNCs) might play a special role in this process by tapping into, and reinforcing the expansion of, the emerging localised capabilities by establishing subsidiaries (be these newly acquired firms or greenfield investments), and providing them with access to financial resources, knowledge and markets.

Nevertheless, the extent to which these processes can support a region's localised capabilities depends on whether the subsidiaries are allowed to operate autonomously. Excessive control on the part of the parent firms might mean that the subsidiaries are less able to cooperate with other regional businesses and to co-create with them localised capabilities. Moreover, the ability of local subsidiaries (and the local industry) to adapt to disruptive innovations might be curtailed by the restrictions imposed on subsidiaries' operations (Østergaard & Park, 2015; Østergaard et al., 2017).

Cooperation between universities and businesses can also reinforce the development of localised capabilities. This should be especially the case for science-based industries since these are more dependent on the knowledge produced at universities, and hence on university activities (Pavitt, 1984). Drucker and Goldstein (2007) identify several different activities, including the creation and commercialization of knowledge, training of students and the application of existing know-how in collaboration with external partners, through which universities contribute to the development of localised capabilities in industries.

The extent to which the university focuses these activities in a regional industry can be seen as part of co-evolutionary processes in which some of the educational, research and entrepreneurial activities of a university support the expansion of an emerging industry; and industrial expansion further incentivises the university to commit efforts to that industry.

The model developed in Figure C.1 shows how self-reinforcing feedback loops between university-industry interaction, the localised capabilities that are relevant to the industry, and industry growth can take place. In industries that are at an early stage of their life cycle, new producers enter an emerging market to introduce new products and services (Klepper, 1997)[1]. Some of the educational, research and entrepreneurial activities developed by a university can cater to the needs of the regional industry that is at an early stage in its life cycle, further supporting its growth. The expansion of the focal industry, in turn, stimulates further the university to commit efforts to the industry.

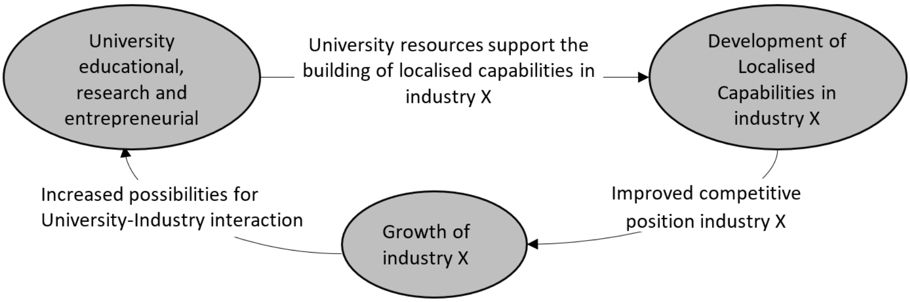

Figure C.1: Conceptual model of the creation of localised capabilities through university-industry interaction.

In our analysis, we aim to focus on the stages depicted in the shaded ovals in Figure C.1. We nevertheless assume the presence of the processes, depicted by the connecting lines, by which the stages indirectly affect each other. Furthermore, although we acknowledge that the region is not a closed system, and the feedback loops are also present across regional boundaries, our interest is on university-industry interaction at the regional level. The analysis centres on the effect of the creation and commercialization of knowledge, training of students and the application of existing know-how in collaboration with external partners by the university. We focus on these university activities because the literature suggests that they represent a key part of university-industry interaction, concerning the industries that we have chosen in this paper (Nilsson, 2006b; Stoerring, 2007; Stoerring & Dalum, 2007).

We argue that the initial size of the industry in the early stages of its life cycle (measured by the number of jobs and companies it hosts) might be key. The larger the industry, the more industry actors, the more possibilities for university-industry interaction, resulting in a stronger university reaction of dedicating more resources to activities that will contribute to the devel-

[1]As soon as the market stabilises around a set of customer preferences and a dominant product design, the focal industry is likely to concentrate around a few producers that can tap into process innovation and economies of scale; and further industry growth is likely to be limited. Exceptions to this pattern, however, concern those industries where firms cater a diversity of markets, enabling the entry of new firms specialised in market niches, and continued industry growth (Østergaard & Park, 2015).

opment localised capabilities relevant to the industry. The establishment of MNC subsidiaries in the region provided that they are endowed with some autonomy by the parent company can also reinforce university-industry feedback loops, by promoting the growth (and thereby the size) of the industry.

For example, the emerging industry might tap into educational programmes developed by the regional university, which support its necessities. The university graduates contribute to the development of the industry's localised capabilities, which in turn leads to stronger demand for graduates by the industry. The hiring of graduates by the growing industry might stimulate the university, in turn, to devote an increasing amount of resources to those programmes that support the needs of the industry. Hence, a series of feedback loops would take place between the university and the industry: the industry would hire more graduates, and the university would dedicate more resources to educational programmes related to the needs of the industry. These feedback loops would support the development of localised capabilities by the industry, and its expansion, resulting in further feedback loops, and a larger number of workplaces at the end of the period studied in the paper.

Note that the university is far from a passive actor in this process; the university is developing at the beginning of the process educational programmes that cater a broad range of needs, beyond those of the regional industry. The university develops, for instance, programmes attending the needs of other industries than the focal one at the regional, national or international level; as well as public sector or broader social needs. It might furthermore develop educational programmes connected to research activities in promising new knowledge fields. The point is that some of this educational activity might fit the skills needs of a regional industry in the early stages of its life cycle; and the hiring of graduates from the focal university is more likely to incentivise the expansion of the industry, and further feedback loops, the greater the size of the industry. While students also display some autonomy in these dynamics by having a preference for what to study, which does not necessarily match with the educational offerings of universities, universities can play an influential role and attract more students in particular fields by opening new and investing in current programs. Similar processes could take place concerning the creation and transfer of university knowledge, and the generation of university spin-offs.

3 Methodology

3.1 Research approach

This paper relies on two case studies: the interaction between AAU and the ICT industry; and the interaction between AAU and the biomedical industry. The case study method allows tracing back in time how the development of each industry might have stimulated actions on the part of the university, and vice versa (Yin, 2014). In both cases, the unit of analysis is the interaction that takes place between the university and the industries, in the context of the North Denmark region. The cases, therefore, are defined according to the phenomena studied (Piekkari, Welch, & Paavilainen, 2009), which are university-industry feedback loops at the level of the North Denmark region. While taking into account that university-industry interaction often goes well beyond the regional setting, spanning to the national and international level (Drejer et al., 2014b; Laursen et al., 2011; Rodríguez-Pose & Fitjar, 2013), the present paper intends to uncover how regional university-industry feedback loops can contribute to industrial development at the regional scale.

The cases are selected based on their outcome: both concern science-based industries with a strong connection to the local university (Stoerring, 2007; Stoerring & Dalum, 2007), yet their success in forming localised capabilities has differed notably. The goal, here, is to understand the processes behind the differing outcomes (Ragin, 2009). Admittedly, the choice of cases entails limitations in the transferability of findings: the regional context plays a key role in shaping the phenomena studied (Welch et al., 2011). On the other hand, this case study strategy aimed at developing a contextualised explanation; that is it enables to uncover explanations that are specific to particular contexts, and that could be further extended in additional case studies aimed at identifying empirical regularities; leading in the long run to theory building (Tsang, 2013).

The case study relies on the combination of qualitative and quantitative research methods. The qualitative methods include the analysis of secondary sources such as policy reports, newspaper articles, and publications in academic journals. Also, three interviews were conducted with managers from the regional administration, the Biomed Community cluster (an organisation linked to the biomedical industry); and the BrainsBusiness cluster (an organisation related to the ICT industry). These interviews allowed the validation of parts of the data obtained from secondary sources while also providing complementary insights.

As for the quantitative methods, these include the analysis of descriptive macro-data from AAU, descriptive macro-data available online from Statistics Denmark, and micro-data of all inhabitants and companies in Denmark from the Integrated Database for Labour Market Research (abbreviated in Danish as IDA) from Statistics Denmark (Timmermans, 2010). The quantitative data is used to give insight into the growth of industries, the recruitment of university and AAU graduates by the industries over time, student numbers, and the research performance of AAU. This data complements the findings from the qualitative methods: while qualitative secondary sources allow following the start of educational programmes, research centres or entrepreneurial activities supporting the ICT and biomedical industry by the university, the quantitative data allows tracking the changes in the workforce of these industries and the employment of AAU graduates. Similarly, the interviews surfaced educational, research and entrepreneurial activities developed by AAU to support the development of the focal industries (for instance, the initiation of university-industry linkages by university graduates; or the establishment of research centres suited to industry needs), whose effects are subsequently assessed by the quantitative data. In this way, the quantitative data triangulates the findings from the qualitative analysis.

The analysis of the IDA database is limited to the North Denmark region, the individuals of interest being those that live and work in a full-time job[2] in the region between 1980 and 2010: the analysis with the IDA database ends in 2010 because of restrictions in the information available on full-time/part-time employment status. The analysis takes into account whether the individual holds a university degree and whether the latest degree has been obtained from AAU (the university is constrained to the main campus in Aalborg[3], due to the focus on North Denmark). The ICT and biomedical industries are defined using the EU NACE classification of economic activities (Eurostat, 1996). Although the firms related to these industries can be found in numerous groupings, we focused on the main ones, in order to minimise noise (see Appendix A for a list of the industry groupings included).

3.2 The regional setting and characteristics of Aalborg University

North Jutland has been historically a region specialised in traditional industries: branches related to construction (quarrying, non-metallic mineral products) or shipbuilding (fabricated metal products) industries have been overrepresented when compared to the Danish average; and this is also the case for industries such as food and agriculture, or the manufacturing of tobacco (Nilsson, 2006b; Pedersen, 2005).Within this context, AAU started as a university combining a technical imprint with a large share of degrees

[2]This is done in order to study industry dynamics: full-time employees are more likely to develop their career within the boundaries of the industry, whilst part-time employment might respond to short-term needs (Richards & de Polavieja, 1997).

[3]Aalborg University has also smaller campuses in Copenhagen and Esbjerg (in the southern part of Denmark).

in social sciences. This mixed character is still visible: in 2017, 40% of the students were enrolled in one of the degrees of the technical and natural science faculties, 48% if the Faculty of Medicine is included in the calculation. Together with Medicine, the university is based on four other faculties (Humanities, Social Sciences, Engineering and Science, the Technical Faculty of IT and Design) from which the Faculty of Social Sciences is the largest, with 6,287 students (30%). The university has campuses in three cities of which the Aalborg campus hosts most of students (82%)(Aalborg University, n.d.-c).

Compared to other universities, a large share of the graduates moves to other regions: only 54% of Aalborg University graduates (with a bachelor, master or PhD degree) who entered the labour market between 2000 and 2010 did so in North Denmark, a significantly lower proportion than that of the other Danish universities. Moreover, 65% of AAU graduates who established their first firm between 2001 and 2010 did so in the same region, the lowest percentage compared to the rest of higher education institutions. This trend is related to the small size of the local labour market in relation to the number of students trained at the university, resulting from a high share of students coming from other regions to study at AAU, who are more likely to move after graduation back to their home region or another region. In fact, 49% of the AAU students graduated between 2000 and 2010 came from regions other than North Denmark, the largest proportion among Danish universities (Drejer et al., 2014b, 2014a). Thus, Aalborg also plays an important role as educational institution at the national level.

4 Aalborg University: creating and being shaped by localised capabilities

4.1 Context: a regional struggle and a university initially focused on traditional industries

Assessing the specific role of AAU in our two cases requires an understanding of the regional context in which they are situated. The very origins of AAU are grounded in the needs of the surrounding region of North Jutland (the northern part of the Jutland peninsula, currently under the administration of the North Denmark region). With 587,335 inhabitants in 2017, (211,937 of them in Aalborg municipality), it is the least populated region in Denmark(Statistics Denmark, n.d.). Before the inauguration of the university in September 1974, some of the main regional actors (employers, unions and the Aalborg municipality) had been lobbying for its creation. One of the key steps in this process was the creation in 1961 of the North Jutland Committee for Higher Education, an organisation headed by a local bank manager and composed of representatives from the municipality, the Danish Parliament (an MP from North Denmark) and the business community (Nilsson, 2006b; Plenge, 2014; Skaarup, 1974). The group succeeded in persuading the Ministry of Education to authorise the establishment of the Denmark Engineer Academy (DIA) in Aalborg.

Nevertheless, during the 1960s the Ministry was reluctant to facilitate the creation of a university in the region. Instead, a law draft submitted in March 1969 opted for the creation of a centre for higher education in Roskilde. The government perceived that it was necessary to cover the growing need for higher education institutions in the country, yet preferred to prioritise the regions surrounding Copenhagen (Plenge, 2014).

The resistance on the part of the Ministry of Education to satisfy the demands of North Jutland led to the creation, by the Committee, of the North Jutland University Association in June 1969. This position gained further support in the same year when 1,000 youngsters from the region demonstrated in front of the Christiansborg Palace, the site of the legislative, executive and judicial powers. Inside the parliament, a majority supported the association plans (Folketings-redaktion, 1969; Plenge, 2014; Pyndt, 1969; Statsministeret, n.d.). Shortly afterwards, a new university law draft included the promise of establishing a higher education institution in Aalborg between 1974 and 1975 (Koldbæk, 1974). The DIA and other higher education institutions present in the region would be integrated into the new Aalborg University Centre, founded in 1974 and re-named as Aalborg University in 1994 (Aalborg University, n.d.-a; Nilsson, 2006b; Plenge, 2014).

The resulting university combined a strong technical character with a large share of social science degrees. Although the technical specialisation was reduced over time by the expansion of social sciences, it still reflected the needs of the regional industries at that time, such as shipbuilding and construction. The student intake of Aalborg University was 1,635 students in 1974, 765 of them in the Faculty of Engineering and Science, 681 in the Faculty of Social Sciences and 189 in the Faculty of Humanities. At that time, the Aalborg University Centre trained graduates in construction for the building industry; while mechanical engineering graduates were employed by companies such as the Aalborg Shipyard (Nilsson, 2006b). Over time the university experienced rapid growth, and with 20,654 students in 2017, it is the fifth-largest higher education institution in Denmark (Danske Universiteter, 2019; Aalborg University, n.d.-b).

In parallel, AAU pioneered together with Roskilde University the Problem-Based Learning (PBL) method in Denmark. This approach to learning entails that students work in project teams on self-defined, interdisciplinary problems, many of them related to challenges faced by local firms. In this respect, PBL offers various advantages for businesses: firms can host students while they develop their projects. Through these projects, students can help firms in solving specific problems; and businesses can screen suitable candidates for their workforce. Moreover, PBL projects have increased the interest of SMEs in hiring AAU graduates (Gregersen et al., 2009). The number of projects grew to the point that in recent years AAU continuously hosts between 2,000 and 3,000, and in 2016 53.1% of the master theses were undertaken in collaboration with businesses or other external partners (Aalborg University, 2017; Kendrup, 2006). Industries such as construction and shipbuilding continued to exist into the 1980s, and during that decade their weight in North Denmark employment was above average compared to the overall Danish labour market. In other regional strongholds, such as the food, beverage and tobacco industries, North Denmark employment was also higher than the average share in Denmark (Pedersen, 2005). Nevertheless, employment in agriculture, fishing and forestry was halved between 1983 and 1999; and shipbuilding experienced a major crisis, together with the rest of the industry in the other parts of Denmark, leading to the closure of shipyards like Aalborg Værft and Danyard Frederikshavn. These closures led to the establishment of spin-offs (Holm et al., 2017) and a growing specialisation in the provision of services such as ship maintenance and repair (Hermann, 2015). Within this context, the transformative role of the university was quickly put into practice, as will be shown in the first case.

4.2 Case 1: AAU adapts (and supports) activities related to the ICT industry

The 1980s and 1990s saw the expansion of the ICT industry in North Denmark. According to the IDA database, the industry workforce increased from 2,203 to 3,786 jobs between 1980 and 1990 and reached a peak of 9,022 employed persons by 2001[4](see Figure C.2). These developments reflected the rapid expansion of the businesses specialised in wireless communications in North Denmark and the growth of their number to 40 in 2000 (Dalum et al., 2005). The origins of this transformation can be found in the entry in the 1960s of SP Radio, a radio and TV manufacturer, in the market of radio communications for maritime vessels. The emergence of spin-offs followed the success of this company. One of these companies would move in the early 1980s into the emerging mobile phone market, whose expansion was propelled by the introduction of the Nordic standard for Mobile Telephony (NMT) in 1981. The success of the NMT standard and the boom of the market favoured a new round of spin-offs from these firms (Dahl et al., 2010; Dalum et al., 2005). At that point, the state of the ICT industry can be aligned to that of an industry at the initial stages of its life-cycle (Klepper, 1997), with new rounds of spin-offs trying to cater an emerging demand for mobile phones.

[4]The trend displayed here is similar to the findings of Pedersen (2005), however there are some slight differences in the definition of the ICT industry.

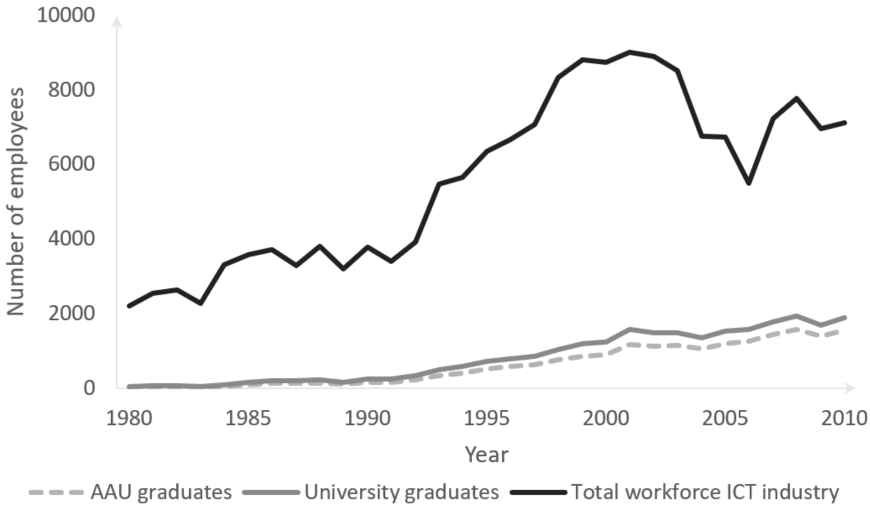

Figure C.2: Number of employees in North Denmark's ICT industry. Source: Own elaboration with data from Statistics Denmark.

The nascent ICT industry tapped into already existing educational and research activities at AAU, that could support the human capital and research needs of its firms. ICT businesses could approach the 200 academic members that AAU employed from its very start in two electrical engineering departments (Dalum et al., 2005; Stoerring, 2007; Stoerring & Dalum, 2007). Shortly after its foundation, AAU established the Department of Electronic Systems in 1979. Over time, the university acquired a prominent position in international rankings in areas related to ICT research, such as mathematics and computer science (CWTS Leiden University, 2017). The firms in the ICT industry tapped into AAU's educational and research activities to acquire human capital and increase their innovation capacity.

The importance of the AAU's educational activities for the ICT industry is best visible when using the IDA database to look at the share of the university graduates in the industry. The solid grey-line in Figure C.2 indicates a growing number of university graduates employed in the ICT industry, while the dashed grey-line in Figure C.3 shows that AAU increased its importance as a supplier of graduates. By 2000, 73% of university graduates in the local ICT industry had been trained by the AAU. Like in the previous figure, most of the increase is concentrated in the 1980-2000 period: the share of AAU graduates in ICT graduate employment grew from 40% to 63% between 1980 and 1990, and to 73% in 2000. This suggests that AAU played an important role, by enabling and keeping pace with the growth of the ICT industry, which otherwise would have been limited in the development of localised capabilities due to high-skilled labour shortages at an early stage of its industry life cycle. In addition, the data also points towards an increasingly intense relationship between AAU and the ICT industry, owing to the growing predominance of AAU graduates in the industry's graduate workforce.

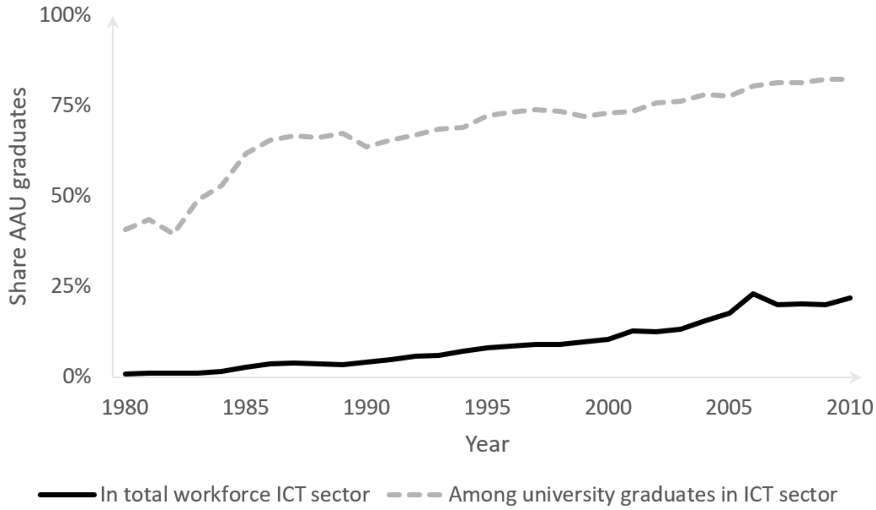

Figure C.3: Share of AAU graduates in North Denmark's ICT industry. Source: Own elaboration with data from Statistics Denmark)

The jump from 1G to the 2G cellular telephony standard during the second half of the 1980s represented another feedback loop between university and industry. Staff members of the Department of Electronic Systems contributed together with the city council and a local bank to the establishment of the NOVI science park at the university campus between 1987 and 1989. The park aimed at promoting the development of wireless communications start-ups, but it eventually provided a site where two of the major companies in the cluster, Dancall and Cetelco, could work together in the development of the technology for a 2G terminal. Their joint venture, DC Development, succeeded in the task in 1992, although the parent firms were acquired by Amstrad and Hagenuk, due to financial problems derived from the technological jump (Hedin, 2009; Østergaard et al., 2017; Stoerring, 2007; Stoerring & Dalum, 2007).

The establishment of the NOVI science park can be seen as an additional research effort of AAU in support of an emerging ICT industry, in particular of those businesses interested in the leap towards GSM phones. AAU staff was also actively involved in the establishment of the ICT cluster organisation, NorCOM, that settled in the NOVI premises in 1997 (Nilsson, 2006b; Stoerring, 2007; Stoerring & Dalum, 2007). Currently, the science park hosts

100 companies and 1,000 employees from which the majority are active in the ICT industry (NOVI, n.d.).

In 1993, shortly before the start of NorCOM, the university committed additional research efforts in areas related to the ICT industry, with the opening of the Centre for Personal Communication (CPK). The start of CPK suggests another feedback loop, in which the research efforts of the university further supported the growth of the ICT industry. The main goal of this centre was to develop basic research on radio communications technology and speech recognition, with the involvement of university researchers and employees from businesses specialised in wireless communications (Dalum et al., 2005; Østergaard & Park, 2015). In 2004 its successor, the Center for TeleInFrastruktur (CTIF), was established (Dalum et al., 2005; Hedin, 2009).

The co-creation of localised capabilities between ICT firms and AAU in the 1990s, nevertheless, cannot be fully understood without taking into account the role played by MNCs. Through newly established subsidiaries, these firms provided the emerging industry with access to finance, knowledge and markets, thereby stimulating its growth (Østergaard et al., 2017; Østergaard & Park, 2015). Indeed, the involvement of foreign firms in the industry helped overcome the financial constraints that local firms faced, which could have prevented the expansion of the industry: one example of this is the acquisition of Dancall and Cetelco by Amstrad and Hagenuk, after these firms had been drained by the financial effort involved in supporting DC development. Many other foreign firms entered into the industry through greenfield investments or local acquisitions in the 1990s and 2000s[5], and the regional subsidiaries of these multinationals focused on developing their R&D activities with the goal of exploiting the local knowledge base of the ICT industry. Moreover, these firms tapped into the AAU's research and graduates, further fuelling the development of localised capabilities in the field of ICT (Østergaard et al., 2017). The CTIF, for example, received funding from some of the largest MNCs in the industry in the 2000s, such as Samsung, Siemens and Nokia, as well as funds from local firms and foundations, and the EU (Dalum et al., 2005; Hedin, 2009).

Previous research also suggests, however, that the way in which MNCs managed their subsidiaries also hindered the development of localised capabilities in the 2000s (Østergaard et al., 2017; Østergaard & Park, 2015): after the burst of the dot-com bubble at the beginning of the decade, some of the MNCs present in the region moved R&D activities to their home countries. Because of the restrictions set by their parent companies, the remaining subsidiaries had limited margin of manoeuvre and autonomy in developing

[5]In the 1990s firms such as Analog Devices, Lucent, Bosch Telecom, Maxon, Texas Instruments, L.M. Ericsson, and Nokia established subsidiaries in the region. The same can be said in the 2000s of multinational corporations such as Flextronics, Siemens, Infineon, Motorola, and Intel (Østergaard et al., 2017)

their R&D strategies and in cooperating with competitors, and they focused on narrow R&D in specific technologies, rather than on multiple parts of the value chain or a wider variety of technologies. As a result, their ability to respond to disruptive innovations was curtailed. This was the case of the shift from the 2G to the 3G cellular telephony standard (some of the parent firms preferred to continue exploiting the 2G standard until it became non-competitive); or the entry in the market of Apple and Google with the iOS and Android systems, between 2007 and 2008. The economic recession that affected Denmark between 2008 and 2010 deepened the effect of this technological disruption.

These shocks led to a wave of closures. Through the decade, many of the foreign MNCs decided to reduce their activities in the region or leave altogether (Østergaard et al., 2017; Østergaard & Park, 2015), and this is visible in the IDA database: between 2001 and 2007, the number of jobs dropped from 9,022 to 7,233 (see Figure C.2). Although changes in the NACE classification between 2007 and 2008 prevent a full comparison, the data points to the effect of the recession that hit Denmark at the end of the decade. Total employment decreased from 7,780 to 6,972 jobs between 2008 and 2009, although the latest record (2010) suggests a slight recovery, to 7,133 jobs. In the aftermath of these developments, NorCOM was integrated into the BrainsBusiness cluster organisation (a public-private partnership in which AAU, Aalborg and the region take part)(Østergaard & Park, 2015). Contrary to NorCOM, the focus of BrainsBusiness goes beyond wireless communications, covering other parts of the ICT industry (Lindqvist et al., 2012).

Despite the shocks suffered by the ICT industry, the data does not suggest a substantial decrease in the interactions between this industry and AAU. BrainsBusiness organises, according to one of its managers, networking activities between ICT firms and AAU researchers to promote research collaboration, and tries to promote firm involvement in PBL projects, which can be seen as a combination of research and educational involvement on the part of the university. However, connections between businesses and researchers tend to rely on pre-existing networks set by employees trained at AAU (interview BrainsBusiness). Hence, there appears to be a continuity in the research links between AAU and the ICT industry, supported by employee links. The fact that Drejer and Østergaard (2017) observe that having employees trained by the AAU positively correlates with the likelihood of firms collaborating for innovation with AAU, also suggests that research collaborations are supported by the links that these employees provide between their companies, and the university.

The data from the IDA database, in addition, suggests that the AAU's importance as a provider of graduates to the ICT industry has increased along the 2000s. Figures C.2 and C.3 show that the proportion of AAU-trained professionals over graduates has grown from 73% to 81% between

2000 and 2008, and to 82% in 2010; although the absolute numbers have shifted with the turbulences experienced by the industry: The number of AAU graduates in the industry dropped from a peak of 1,165 in 2001 to 1,064 in 2004, but by 2007 it had already recovered to 1,452; and 1,559 AAU graduates worked in the industry in 2010.

In sum, it can be said that AAU has contributed, while developing its educational and research activity, to the development of the localised capabilities which have made North Denmark an attractive region for ICT firms, which is visible in the growth in the number of industry jobs. At the same time, the growth of these businesses ensured that more resources were dedicated to promoting education and research activities connected to the ICT industry. Indeed, much of the current interactions can be seen as a consequence of the feedback loops between AAU and the ICT industry: even when the BrainsBusiness staff try to build networks between SMEs and university researchers, many of these businesses already employ AAU graduates with existing acquaintances in academia. This organisation also promotes the participation of businesses in hosting students, as part of their PBL projects (interview BrainsBusiness). In addition, AAU has been able to achieve scientific excellence in areas related to the ICT industry, such as those of mathematics and computer science (CWTS Leiden University, 2017), and the staff numbers at the faculty of Engineering and Science have grown faster than those of the other faculties at AAU (Aalborg University, n.d.-b). These feedback loops were reinforced by the arrival of foreign multinationals in the region, during the 1990s: by converting local firms into their subsidiaries, they provided the regional industry with access to finance, knowledge and markets, strengthening the expansion of the industry and the co-creation of localised capabilities with AAU. The industry seems to have a reached a stage of maturity in its life cycle, in which some of its players left the region in the 2000s; however, this does not seem to have weakened the intensity of the educational and research efforts developed by the university. The maintenance of the links between AAU and the ICT industry suggests that the vigour of the university-industry feedback loops depends on the extent to which the industry is able to take-off, and grow towards a state of maturity. In order to assess further the relevance of industry growth for university-industry feedback loops, the next section provides a comparison assessing the role that the university played in the development of the biomedical industry.

4.3 Case 2: Attempts to support activities related to the biomedical industry

When the activities of AAU in support of the biomedical industry started in the early 2000s, this industry was at an earlier stage of development compared to the ICT industry and had not reached a critical mass similar to that of ICT. These differences appear to explain why the support activities developed by AAU have not triggered an expansion process like that of ICT: When these educational and research activities started, they encountered an industry whose critical size was insufficient to tap into them and grow. The university has continued supporting the industry, but the slow growth of the biomedical businesses does not suggest that AAU can trigger feedback loops like those observed in ICT. Until now, the life cycle of the biomedical industry in North Denmark has not led to a rapid expansion in the number of its businesses and its size. The developments of the biomedical industry find resonance with those of the rest of the biomedical industry, globally. Despite the success of cluster initiatives like the Medicon Valley in the regions of Copenhagen and Malmö (Pålsson & Gregersen, 2011), the limited pervasiveness of the biomedical industry has limited its growth. So far, it is unclear whether it will be able to produce a technological revolution like that of ICT (Archibugi, 2017; Hopkins et al., 2007; Wydra & Nusser, 2011).

The activities of AAU related to the biomedical industry have been focused around a cluster initiative, which started in 2000 and was formalised in 2003 under the name of Biomed Community. The university had already developed biomedical research, but in that year started collaborating actively with Aalborg Hospital and Aarhus University, under the umbrella of the HEALTHnTECH Research Centre, supporting the development of new products by the industry. The actors involved in the cluster initiative also facilitated the establishment of the Research House facility, next to the Aalborg Hospital. The Research House provides educational and research services, spaces for testing new products and a business incubator. The university also invested resources in the training of graduates, by providing two medical specialisations within Electrical Engineering and starting a degree in Health Technology in 2000 (Aalborg Universitetshospital, 2015; Stoerring, 2007; Stoerring & Dalum, 2007). Hence, the actions developed by the university could have benefited the industry through the creation and commercialization of knowledge, provision of human capital and the application of existing know-how to support innovation in the industry (Drucker & Goldstein, 2007).

The Biomed Community included 35 firms at its start, but many of these worked in the distribution of health care equipment or were small university spin-offs. Others were subsidiaries of large Danish businesses with headquarters in the Capital Region of Denmark, such as Oticon, Novo Nordisk or Coloplast (Stoerring & Dalum, 2007). The analysis of the IDA database in Figure C.4 suggests that these businesses provided only a small company base and that the industry's capacity to absorb university graduates was somewhat limited, providing little ground for the start of a series of feedback loops between university actions and industry demand. As a result, many graduates from degrees with a medical specialisation opted for moving either to other regions in Denmark or to the ICT industry (Stoerring, 2007;

Stoerring & Dalum, 2007). This has been the case despite a further analysis with the IDA database Figure C.5 suggests an increasing involvement of AAU graduates, approaching the levels of the ICT firms.

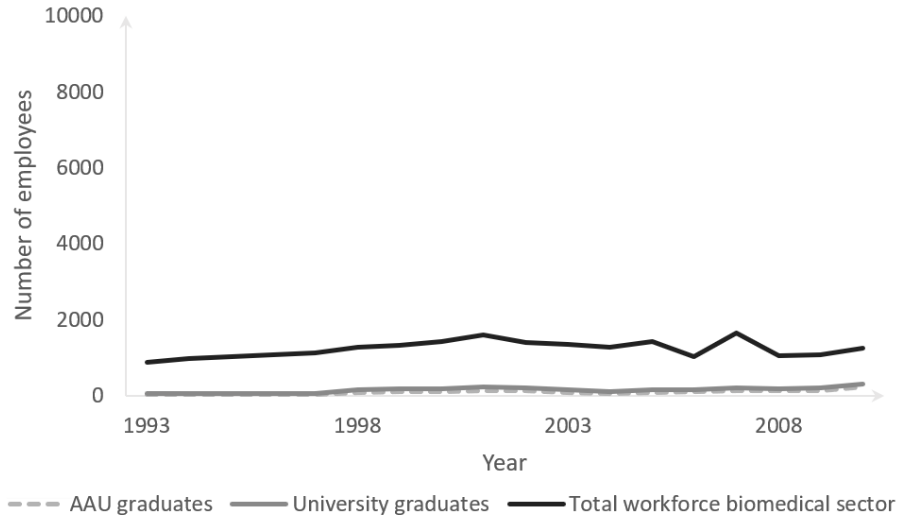

Figure C.4: Number of employees in North Denmark's biomedical industry (excl. hospital). Source: Own elaboration with data from Statistics Denmark).

In addition, the university failed to develop general scientific excellence in the biomedical field, scoring last in Denmark and below average among the universities included in the CWTS Leiden Ranking (CWTS Leiden University, 2017). However, there are some niches in which the university has acquired a prominent position. This is particularly the case for the Centre for Neuroplasticity and Pain, and the Centre for Sensory-Motor Interaction who have prominent positions in their respective fields at the national and international level. This specialisation is also visible in the AAU publication output: most of the AAU's medical publications between 2000 and 2018 are within fields related to these centres such as neurosciences and neurology (1,280 publications, 20.43% of the total, a considerably higher share than other Danish universities) (Danish National Research Foundation, n.d.; Pubmed, 2018; Thomson Reuters, n.d.).

Supporting the view that the biomedical industry in North Denmark has a relatively limited potential for the development of feedback loops with the activities developed by the university, Stoerring argued that the growth dynamics that could lead to an expansion in the number of biomedical firms in North Denmark might take more time than the period she covered (mid-2000s) (Stoerring, 2007; Stoerring & Dalum, 2007). Stoerring also argued that the activities developed by AAU; and the acquisition of a university start-up

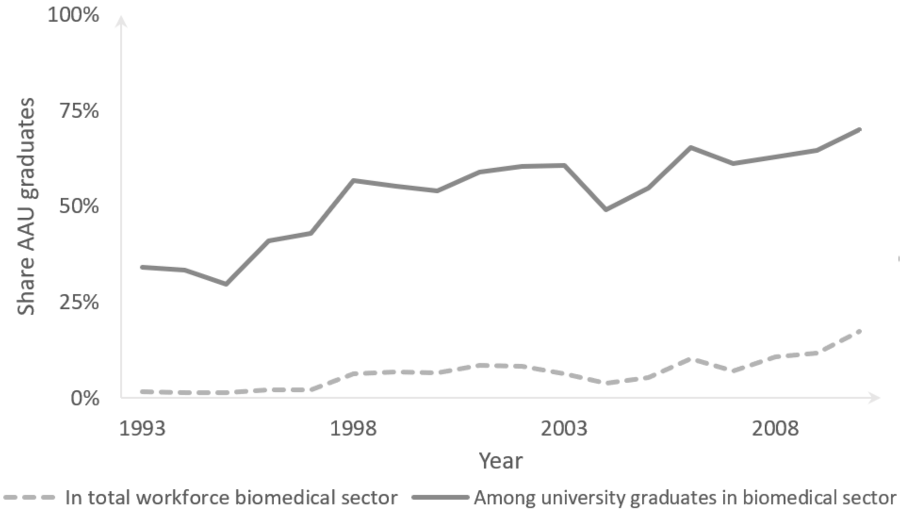

Figure C.5: Share of AAU graduates in North Denmark's biomedical industry (excl. hospital). Source: Own elaboration with data from Statistics Denmark)

(Neurodan) by a German firm (Otto Bock) might trigger the expansion of the industry in the region[6]. However, the analysis of the IDA database up to 2010 (figures C.4 and C.5) suggests that the feedback loops between AAU and the biomedical industry have not stimulated an expansion of the latter, measured as the number of jobs at the end of the period. In fact, most of the graduates already came from AAU by the start of the cluster initiative. If anything, their importance has continued increasing until 2010, yet this trend did not seem to accelerate after 2000. Moreover, with 38 businesses the number of firms in the Biomed Community cluster has not increased substantially (Biomed Community, n.d.).

Despite the lack of feedback from the biomedical industry, AAU has taken part in further efforts to stimulate the growth of these businesses. This is the case of the Empowering Industry & Research Initiative (EIR) in which the university has participated since 2011 (Empowering Industry and Research, n.d.). A number of public actors such as the university, the Aalborg municipality, the regional administration and the Aalborg hospital have been involved in the initiative, investing more resources in the formation of the industry, with various goals in mind (Welch et al., 2011; Østergaard &

[6]Stoerring focused on processes of cluster growth, and hence her research differed from industry studies. Clusters, in fact, can in-clude firms from different industries (Porter, 2000). However, the insights from Stoerring are still useful, given the similarity between the clusters she studied, and the industries compared in this chapter (Stoerring, 2007; Stoerring & Dalum, 2007)

Park, 2015; Østergaard et al., 2017; Hopkins et al., 2007)[7]. The opening of the Faculty of Medicine in 2010, which led to a substantial increase in the medical publication output, might also be seen as another development that could support the biomedical industry (Aalborg University, n.d.-a; Thomson Reuters, n.d.).

5 Discussion and Conclusion

This chapter has given insight in the feedback loops between a university and two industries of its region; and how these processes affect the creation of localised capabilities, reinforcing the competitiveness of these industries and their growth. A conceptual model has been devised, which is applied to the case of the ICT and biomedical industry in the North Denmark region. The data suggest that the industries included in these cases have evolved differently: the ICT industry grew considerably, while the workforce of the biomedical industry remained more or less stable. The conceptual model sheds some light on the role played by university-industry feedback loops in shaping the localised capabilities of the ICT and biomedical industries.

One fundamental aspect here seems to be the employment size and the life cycle of the regional industry during university-industry interaction. The workforce of the ICT industry was larger than that of the biomedical industry at the start of university engagement, and the gap in the size of these industries grew over time. The establishment of foreign MNCs' subsidiaries in the region also seems to have reinforced the feedback loops between ICT firms and AAU: by acquiring local firms, foreign businesses provided access to funding, knowledge and markets to the industry; whilst tapping into AAU's research and education activity to the point of financing research centres such as CTIF. As expected in the conceptual model, the difference in the size of the industry seems to have influenced the extent to which the industries could tap into the education, research and entrepreneurship activities already developed by the university; and thus the start of university-industry feedback loops. The employment size of the ICT industry facilitated the start of a series of feedback loops and the creation of localised capabilities strengthening the position of the businesses and their expansion until the industry faced a series of crises at the beginning of the 2000s. The effect of these crises, in turn, seems to have been increased by the lack of flexibility that foreign MNCs imposed on their subsidiaries when exploring different technologies or cooperating with other businesses in the region. These restrictions might

[7]University professionals, for example, are interested in being able to train medical doctors in order to stimulate health professionals' involvement in the development of research (Stoerring, 2007; Stoerring & Dalum, 2007). Another reason is to ensure that the region retains a university hospital (interview regional expert)

have curtailed the ability of the subsidiaries to co-create localised capabilities between them, and with the university (Østergaard & Park, 2015; Østergaard et al., 2017).

Meanwhile, the smaller size of the biomedical industry seems to have prevented the co-creation of localised capabilities through university-industry interaction, despite the presence of multinational subsidiaries in the region. So far, the life cycle of the biomedical industry has not led, in the region to a critical mass of businesses that can tap into AAU activities to grow. University actions are unlikely to generate the localised capabilities that will guarantee the competitiveness of the industry and its growth. The creation of localised capabilities depends on the extent to which a university and an industry can influence each other via feedback loops. In this sense, this chapter complements the research conducted by Stoerring, who observed weaker growth dynamics in the biomedical firms of North Denmark than in their ICT counterparts, until the mid-2000s (Stoerring, 2007; Stoerring & Dalum, 2007). Our research covers later years in the development of the biomedical industry (until 2010), observing that this industry has not experienced the growth dynamics observed in the ICT industry.

Here, another important factor might have been the presence of inter-industrial competition for labour, similar to the Dutch disease; in the early days of the ICT industry competition for labour was limited and the growing ICT industry could absorb workers that were laid off by the declining traditional industries. However, the biomedical industry faces a much stronger competition for labour due to the presence of the ICT industry, in which people with a medical degree, or a degree with a medical specialisation, can also find employment. In this respect, the findings from previous research suggest that this could be the case: in the early years of the Biomed Community cluster initiative, health technology professionals experienced difficulties in finding jobs in the biomedical industry, common alternatives being emigration to other regions of Denmark or employment in the ICT industry (Stoerring, 2007). Moreover, our research with the IDA database indicates that the ICT industry was at its employment peak by 2001, shortly after the start of the biomedical cluster initiative, and its employment size has not diminished substantially afterwards, despite shocks such as the burst of the dot-com bubble or the shift from the 2G to the 3G cellular standards. This is especially the case of the number of university graduates, which has proved to be particularly robust.

The insights delivered in this chapter contribute to the university-industry interaction literature by offering a contextualised explanation of how university-industry feedback loops stimulated the development of specific industries. The findings suggest that, in North Denmark the extent to which universities and nascent industries co-create regional localised capabilities depends on the size of these industries during industry-university collaboration, as measured by industries' number of employees and companies. Because this is an explanation in principle applicable to a context like the one reviewed in the chapter; the findings are, for now, transferable to similar cases. Further research, providing insights on cases whose context differs from that of the present chapter, could extend the reach of our findings, identifying empirical regularities and proposing new theory on how university-industry interactions relate to the formation of localised capabilities in different types of regions.

With all these words of caution, the findings also suggest implications for regional innovation policies. The lack of strong bottom-up dynamics at the industry side (that is, the absence of industries that experience strong growth as part of their life cycle) might pose a challenge to policies relying on universities as main drivers of regional development. Both parts, university and industry, seem to be necessary for the development of localised capabilities. In a way, these suggestions are similar to the smart specialisation strategy approach (Asheim, 2014), basing innovation policies on the existing strengths of the regions: policymakers might be interested in developing new industries, but if these developments do not build from already existing developments, they are less likely to thrive. The same might go for the role of the university as a trigger for regional development.

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A Variables used in quantitative analyses

List of the variables included in the quantitative analysis, as they are available in the Danish Integrated database for Labour Market Research (IDA, in Danish). The data for these variables could be merged into a common dataset, using personal identification numbers. The variables for the industry in which the individual is employed (PDB932, PDB03) are only available for some of the years covered in the analysis, as indicated below. More information about the IDA database is provided by Timmermans (2010).

Table C.1: Variables used in quantitative analyses.

Variable	Variable Name	Specification
Institution of highest completed education	HFINSTNR	Aalborg University: 280776, 851416, 851446 Universities (including PhD schools): 101441, 101455, 101530, 101535, 101560, 101582, 147406, 151413, 173405, 265407, 265415, 280776, 280777, 280778, 280779, 280780, 280781, 280782, 280783, 280784, 280785, 280786, 280787, 280788, 280789, 280790, 280791, 280833, 280834, 280835, 280836, 280837, 280838, 280839, 280840, 280841, 280843, 280844, 280845, 280846, 280847, 280848, 280849, 280850, 280857, 280858, 280859, 280860, 280861, 280904, 280907, 313402, 330401, 461416, 461437, 461450, 537406, 561408, 561411, 621406, 657410, 751418, 751431, 751453, 751465, 851416, 851446

Continuation of Table C.1

Variable	Variable Name	Specification
Industry where the individual is employed	PDB932 (1980-2003)	NACE1(.1) 1980-2007 ICT industry: Manufacture of office machinery and computers (30), Manufacture of radio, television and communication equipment and apparatus (32), Computer and related activities (72), Telecommunications (642), Research and experimental development on natural sciences and Engineering (731), Reproduction of computer media (2233), Manufacture of insulated wire and cable (3130), Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment (3320), Wholesale of electrical household appliances and radio and television Goods (5143), Wholesale of office machinery and equipment (5164), Wholesale of other machinery for use in industry, trade and navigation (5165), Wholesale of computers, computer peripheral equipment and software (5184), Wholesale of other office machinery and equipment (5185), Renting of office machinery and equipment, including computers (7133) Biomedical industry (without hospital and related activities): Manufacture of pharmaceuticals, medicinal chemicals and botanical products (244), Manufacture of medical and surgical equipment and orthopaedic appliances (331), Research and experimental development on natural sciences and Engineering (731), Wholesale of pharmaceutical goods (5146)

Continuation of Table C.1

Variable	Variable Name	Specification
Industry where the individual is employed	PDB03 (2004-2010)	NACE2 2008-2010 ICT industry: Telecommunications (61), Computer programming, consultancy and related activities (62), Manufacture of electronic components and boards (261), Manufacture of computers and peripheral equipment (262), Manufacture of communication equipment (263), Manufacture of irradiation, electromedical and electrotherapeutic equipment (266), Manufacture of optical instruments and photo-graphic equipment (267), Manufacture of wiring and wiring devic-es (273), Software publishing (582), Data processing, hosting and related activities; web portals (631), Repair of computers and communication equipment (951), Manufacture of instruments and appliances for measuring, testing and navigation (2651), Manufac-ture of office machinery and equipment (except computers and peripheral equipment) (2823), Repair of electronic and optical equipment (3313), Construction of utility projects for electricity and telecommunications (4222), Wholesale of computers, comput-er peripheral equipment and software (4651), Wholesale of electronic and telecommunications equipment and parts (4652), Other research and experimental development on natural sciences and engineering (7219), Renting and leasing of office machinery and equipment (including computers) (7733) Biomedical industry (without hospital and related activities): Manufacture of basic pharmaceutical products and pharmaceutical preparations (21), Manufacture of medical and dental instruments and supplies (325), Wholesale of pharmaceutical goods (4646), Research and experimental development on biotechnology (7211), Other research and experimental development on natural sciences and engineering (7219)

Continuation of Table C.1

Variable	**Variable Name**	**Specification**
Location of employment	ARBKOM	Municipality codes are used to determine the region, in which the individual's workplace is located (according to the most recent geographical map of Denmark)
Type of employment (full-time/part-time)	PJOB	Full-time employment if PJOB=1

Paper D

The effect of university-industry collaborations on firm-level human capital

Gerwin Evers

Working Paper

The layout has been revised.

Abstract

A common firm-side rationale for university-industry collaborations is the strengthening of their knowledge base. However, cultural distance, limited absorptive capacity, tacitness of the knowledge and absence of social capital can undermine possible university-industry knowledge transfer and thereby inhibit firms from capturing the benefits of the collaboration. The literature ascribes an important role to labour mobility for overcoming similar barriers and thereby facilitate knowledge transfer, while the university-industry literature provides numerous qualitative insights in the hiring of graduate human capital that takes place in the context of university-industry collaborations. This study argues that the hiring of graduates in the context of a university-industry collaboration can play an important role in overcoming the aforementioned barriers, and aims to contribute to the literature by providing quantitative insights in the hiring that takes place in the context of university-industry collaborations.

The analyses utilises a combined data set of the Danish Community Innovation Survey data and longitudinal employment data at the firm level. Subsequently, genetic matching is applied to avoid endogeneity from driving the results. The analysis shows increased hiring of university graduates for firms that are collaborating with universities. Firms are also more likely to hire PhD graduates. By attracting these graduates, firms strengthen their position for overcoming the absorptive capacity and cultural barrier. Furthermore, firms tend to focus their hiring of graduates on graduates trained by their university partner, providing them with social capital and tacit knowledge specific to their university partner which could facilitate the knowledge transfer from this university.

By altering the hiring dynamics, university-industry collaborations have a significant long-term impact on the human capital composition of these firms that is well beyond the timeframe of the collaboration with the university. Therefore, we argue for a more prominent position of hiring as a measure for evaluating the success of university-industry collaborations.

Preface

During my literature review, I read some of my supervisor's work on employee-driven university–industry relationships. His study utilizes a unique asset of the Danish Community Innovation Survey which is a question about collaborations with specific university, which enables the study of university-specific effects. I aimed to extend the findings of this body of research by examining how university-industry research collaborations are related to the hiring strategy of firms. This paper was presented in the Regional Innovation Policies conference in Bergen in November 2018. Currently, it is available as a working paper.

1 Introduction

There has emerged a wide variety of studies addressing the dynamics of university-industry collaborations. A variety of motives for the involvement of academics in these processes have been discussed in the literature (D'Este & Perkmann, 2011). However, the benefits that firms obtain from their involvement in these collaborations are more challenging to establish. While some studies tried to provide insight into the effects of these collaborations on firm performance (Mark et al., 2014), no conclusive evidence has been presented yet. Perkmann et al. (2011) instead pose that firm-side motivations for university-industry collaborations are likely to be not solely based on quantitative success measures. Competition nowadays increasingly depends on the capabilities of firms to acquire and utilize knowledge, while solely relying on internal R&D for this has been deemed undesirable (Chesbrough, 2003). As (Chesbrough, 2003, p. xxvi) noted *"not all the smart people work for us, we need to work with smart people inside and outside our company"*. Perkmann et al. (2011) hence argues that firm-side motivations for university-industry collaborations are likely to be based on strategic considerations such as acquiring knowledge. This is backed up by empirical studies that show that strengthening the knowledge position is indeed an important rationale for a firm's involvement in university-industry collaborations (Broström, 2012; Harryson et al., 2007), as well as the key benefit derived from these collaborations (Lee, 2000). Acquiring this external knowledge introduces firms to potential new solutions and original combinations to existing problems (Hargadon & Sutton, 1997), but can also contribute to the potential for maintaining this capability in the long term.

University-industry collaborations targeted on innovation offer university and industry actors a setting that can enable the interactive co-production and sharing of such knowledge (Canhoto et al., 2016). Compared to other university-industry channels, collaborations are considered to be better suited for transferring tacit knowledge (Schartinger et al., 2002). This co-production requires trust among the actors involved in order to facilitate actors to open up and combine their knowledge bases, inevitably providing the firm the opportunity to evaluate the strategic value of the university's knowledge (Barnes et al., 2002; Van De Ven & Johnson, 2006). This process allows each actor to work from their own expertise and does not require an in-depth understanding of the expertise put-in by their partner. When in time the new knowledge turns out to be useful for the company, it might consider it for different usages, requiring ways to obtain and internalize the knowledge from the university partners.

However, the sharing of knowledge across organisational boundaries can be hindered by a set of factors such as differences in institutional culture

(Boschma, 2005; Bruneel et al., 2010), lacking absorptive capacity (Cohen & Levinthal, 1990), tacitness of the knowledge (Santoro & Bierly, 2006) and the absence of the required social capital (Johnson et al., 2002). Yet assuring this knowledge transfer from the collaboration is key as this being one of the main rationales for the collaboration, which needs to be realised to offset the inherent costs that are associated with every collaboration (Laursen & Salter, 2006). Therefore, firms aiming to utilise their university-collaboration to strengthen their knowledge base need to find ways for overcoming the barriers to knowledge sharing. However, most approaches for overcoming these barriers, such as changing institutional culture or building social capital, require long-term interaction and commitment of resources. The literature stresses the importance of boundary spanners to overcome such barriers for knowledge sharing (Allen & Cohen, 1969; Tortoriello et al., 2012). Considering the importance of these boundary spanners, acquiring these key individuals could be an important step in facilitating the knowledge transfer. Inter-organisational labour mobility has then also been established as an important channel for facilitating the knowledge transfer between organisations (Audretsch & Keilbach, 2005; Song et al., 2003). Also the transfer of academics to industry has been regarded of value in this regard (Zellner, 2003). However, acquiring tenured university staff is likely to be difficult, because of this will take away their stable labour market conditions and introduce them to a different institutional culture (Bruneel et al., 2010; D'Este & Perkmann, 2011).

However, PhD graduates can also span boundaries between academia and industry (Kunttu et al., 2018). Furthermore, undergraduate students are considered to play a role in the transfer of knowledge from university to industry (Kunttu, 2017). The involvement of students in the collaborations offers firms additionally the possibility to screen their potential and thereby reduce their risk in hiring them (Broström, 2012; Harryson et al., 2007). In this way, firms by adjusting their recruitment strategy could help position them to overcome the barriers to university-industry knowledge transfer. Firms could benefit from refocusing their recruitment on university graduates to overcome both the cultural and absorptive capacity barrier. In here firms might acquire some of the tacit knowledge and social capital by specifically focusing on the recruitment of graduates that are trained by their university partner.

Firms also list acquiring additional human capital as one of the objectives for collaboration with a university (Broström, 2012), yet the findings of Lee (2000) suggest that collaboration with the sole purpose of hiring might be not the most common strategy. Hence, firms hiring in the context of university-industry collaborations might specifically be aimed at facilitating the knowledge transfer from the university to their organisation. Through this hiring, a short-term university-industry collaboration can have a long-term impact on the workforce composition of the firm. While the above suggest an important role of graduate hiring dynamics for overcoming barriers to university-industry knowledge transfer, the literature as yet focuses primarily on the potential of the labour mobility of full-time staff for facilitating knowledge transfer (Zellner, 2003). In the studies that assess the role of graduates in the context of university-industry collaborations, the empirical evidence has mainly been qualitative and provide insight into i.a. the rationales for the hiring (Broström, 2012; Harryson et al., 2007; Kunttu, 2017; Siegel et al., 2003). This study aims to contribute to this discussion by providing insights by elucidating the general pattern of how involvement in a university-industry collaboration affects the recruitment strategy of firms. The following question guides this enquiry:

> **What is the impact of university-industry collaborations on the graduate recruitment of firms?**

For answering the above question this study combines longitudinal register data with the results of the Danish Community Innovation Survey, providing data for about 3000 firms on their university-industry collaboration activities, and the hiring behaviour prior and after their eventual collaboration. The analysis employs genetic matching to assess the difference in the hiring of graduates of collaborating versus non-collaborating firms. The analysis showed that firms when collaborating with a university refocus their hiring efforts to graduates, in which companies are more likely to recruit PhD graduates and tend to specifically target graduates trained by their university partner. By providing insights into the firm-side human capital effects this studies contributes to the current understanding of the firm rationales for university-industry collaboration, while also adding to the literature with some insights on how firms can potentially overcome the barriers to university-industry knowledge transfer (Bruneel et al., 2010). These insights can support the discussion regarding the development and evaluation of university-industry collaboration policies.

The following section reviews the literature on the firm-side effects of university-industry collaboration and how collaboration might affect the recruitment of companies. Next sections give insight into the methodology and results. The paper ends with a discussion and conclusion.

2 Lierature Review

University-industry knowledge transfer is deemed an important way for universities to realise their economic impact (Charles, 2006). University-industry collaborations are considered to be an important channel for realizing such a knowledge transfer. Collaborations offer a context for co-producing knowledge and firms might aim to internalise more of the university's knowledge. While the interactive character of these collaborations is regarded to offer relatively good conditions for the transfer of tacit knowledge compared to other university-industry channels (Schartinger et al., 2002), the inter-organisational transfer of knowledge is still a rather multi-faceted process. In this process, sender, receiver, the nature of the knowledge and the inter-organisational dynamics play all an important role to the success of the knowledge sharing (Easterby-Smith et al., 2008).

University-industry knowledge transfer requires companies to have the relevant absorptive capacity to be able to recognize the value of the knowledge, internalize it and apply it within the firm-specific context (Cohen & Levinthal, 1990). Human capital, either in the form of education or work experience, is a key building block of this absorptive capacity (Lund Vinding, 2006). Lacking this absorptive capacity can be the underlying factor for other barriers to university-industry knowledge transfer (Bruneel et al., 2010). In addition, differences in institutional culture might hinder the sharing of knowledge between industry and academia (Boschma, 2005; Bruneel et al., 2010). Changes in absorptive capacity and institutional culture through training staff and upgrading facilities could hence foster the university-industry knowledge transfer, but these changes tend to be long term and resource-consuming (Johnson et al., 2002), if even possible. With the fast pace of technological change, relying on such long-term expensive interventions is likely to not be feasible. This paper argues instead for the use of an outward-oriented perspective for addressing these concerns. Almeida and Kogut (1999) showed that inter-firm mobility of engineers facilitated knowledge transfer between the organizations. Song et al. (2003) argue in line with this that firms can further their interest by strategically hiring of people who carry the required assets to facilitate the knowledge transfer as boundary spanners.

Although individuals can also fulfil this role at the university-industry interface (Zellner, 2003), moving to industry means for tenured academics the loss of labour stability (Crespi et al., 2007). Furthermore, they might be attached to the academic culture that is more driven by research motives and a research logic than is the case in industry (Bruneel et al., 2010; D'Este & Perkmann, 2011). However, it is known that PhD graduates can also span boundaries between academia and industry (Kunttu et al., 2018). Further, undergraduate students are considered to play a role in the transfer of knowledge among university and industry (Kunttu, 2017). University graduates might in this context be suitable candidates, as having high levels of absorptive capacity indicated by their ability in acquiring and utilising knowledge (Lund Vinding, 2006) and their study time have made them to some extent familiar with the institutional culture of academia. That may also explain why Bruneel et al. (2010) observe fewer barriers to university-industry collaborations for firms that employ a larger share of university graduates. Graduates may facilitate with their academic knowledge and familiarity with the academic culture a fruitful university-industry knowledge transfer.

Although recruiting new staff itself is also a resource-consuming process and doing so only for the sole purpose of facilitating knowledge transfer may not always be feasible. However, firms are already repeatedly recruiting new staff to accommodate their growth or replacement of leaving employees. This is, even more, the case for firms involved in university-industry collaborations, as Scandura (2016) found these firms to be more likely to expand their R&D departments and many studies point to the recruitment of university graduates playing some role in the context of university-industry collaborations (Broström, 2012; Harryson et al., 2007; Ishengoma & Vaaland, 2016). Therefore, we expect firms to refocus their recruitment strategy in the context of university-industry collaborations to include more university graduates. Therefore the first hypothesis is:

> *Hypothesis 1: Firms collaborating with a university will increase the share of university graduates among their new hirees*

There is likely to be much heterogeneity in the extent to which graduates have acquired absorptive capacity and familiarity with the academic culture. The more education students have received, the more absorptive capacity they acquired. Similarly, the longer students have been emerged in a university context, the more students are familiarized with the institutional culture present within universities. While there are some differences among and across bachelor and master students in this regard, PhD graduates form a special group by the duration and intensity of their emergence in the university context. This makes it likely that they have acquired more absorptive capacity and more familiarity with the institutional culture than bachelor or master students. Harryson et al. (2007) also sees particular potential for PhD graduates for university-industry knowledge transfer but notes that potential intellectual property rights claimed by the university might complicate this transfer prior to graduation. However, after graduation, the PhD graduates can unshackle them from these restraints and play an important role by moving to industry and facilitate the knowledge transfer at the university-industry interface (Kunttu et al., 2018). The recruitment of graduate was in a few cases even observed to be one of the main mechanism for companies to acquire knowledge from university partners (Lim, 2009). This is also reflected in the findings of Bekkers and Bodas Freitas (2008) in which the employment of PhD graduates is considered to be of importance for university-industry knowledge transfer. Hence we hypothesize the firms involved in a university-industry collaboration are more likely to hire a PhD graduate:

> *Hypothesis 2: Firms collaborating with a university are more likely to hire a PhD graduate*

The knowledge exchanged can vary from the codifiable know-what knowledge consisting of facts, to the more tacit know-why and know-how knowledge in the form of skills, experiences and expert insights. While codifiable knowledge can be easily transmitted via publications, the transmission of tacit knowledge requires intensive interaction (Lundvall & Johnson, 1994). The fact that this latter kind of knowledge cannot be easily appropriated by other firms, makes also that it is deemed to be of crucial importance for fostering innovation within firms (Cavusgil et al., 2003). Trust is crucial in the inter-organisational dynamics to create a context in which knowledge sharing can take place. Absence of trust may let partners fear opportunistic behaviour or be uncertain about the quality of the knowledge transmitted (Easterby-Smith et al., 2008). Inter-organisational social ties can play a role in taking away these concerns, as well as bridge institutional and geographical distances (Bell & Zaheer, 2007). Hence, social capital is understood to play an important role in both the establishment (Drejer & Østergaard, 2017) and the survival of university-industry collaborations (Steinmo & Rasmussen, 2018).

Tacit knowledge and social capital is highly specific to the context in which it is developed. Companies aiming to strengthen their knowledge base in the context of a university-industry collaboration therefore need to acquire tacit knowledge and social capital specific to the university it is collaborating with (Polanyi, 1966; Schuller, 2007). Both the acquirement of relevant tacit knowledge as well as the development of social networks specific to a university requires intensive long-term involvement in that university. While doing this internally in the context of a university-industry collaboration is often not feasible, including these considerations into the recruitment strategy could act as an alternative. The full-time staff of the university partner are the individuals with the strongest developed relevant tacit knowledge and social capital. Yet, tenured positions in academia create considerable opportunity costs for firms to overcome in their efforts to recruit university staff. As a substitute, firms might target their hiring at graduates from their university partner. The immersion of these graduates for several years in the university makes it likely that they have incorporated parts of the university-specific tacit knowledge and developed relevant social capital by interacting with academic staff. In addition, by collaborating with a university, firms acquire insights into the quality of the teaching programs and can consult university staff about the quality of individual students. On occasion, students tend also to be involved in some of the collaboration, which allows firms to screen them for potential later recruitment and thereby reduce the firm-side risks involved in the recruitment process[1] (Harryson et al., 2007). In some cases the screening and recruitment of graduates might even be considered one of the prime aims of collaboration (Broström, 2012), yet the findings of Lee (2000) suggest that this is only the case for some collaborations. Follow-

[1]Universities could also adapt their teaching programs in response to university-industry interaction (Deutch, 1991; Broström, 2012), but these processes are considered to be more long-term and beyond the scope of this study

ing the above arguments, firms may aim to acquire relevant tacit knowledge and social capital by focusing on the recruitment of graduates trained by their university partner. Hence, we hypothesize:

> *Hypothesis 3: Firms collaborating with a university will focus their hiring of graduates on graduates trained by their university partner*

Table D.1 summarises the hypotheses.

Table D.1: Overview hypotheses.

Hypothesis	Barrier	Focus recruitment on
1	Absorptive capacity and institutional culture	University graduates
2	Absorptive capacity and institutional culture	PhD graduates
3	Social capital and tacit knowledge	Graduates from collaboration partner

3 Methodology

3.1 Research approach

Despite the wide range of qualitative and quantitative research into the rationales for collaborating with universities, data limitations often complicate the testing of these hypotheses. One of the main obstacles is that not only data on collaborations of individual companies is required, but also on the hiring behaviour displayed by these firms in the period around the collaboration. Furthermore, university-industry collaborations are scarce, especially if collaborations with specific universities are considered. For this study, we have obtained access to two datasets that provide this data for a large sample of firms in Denmark.

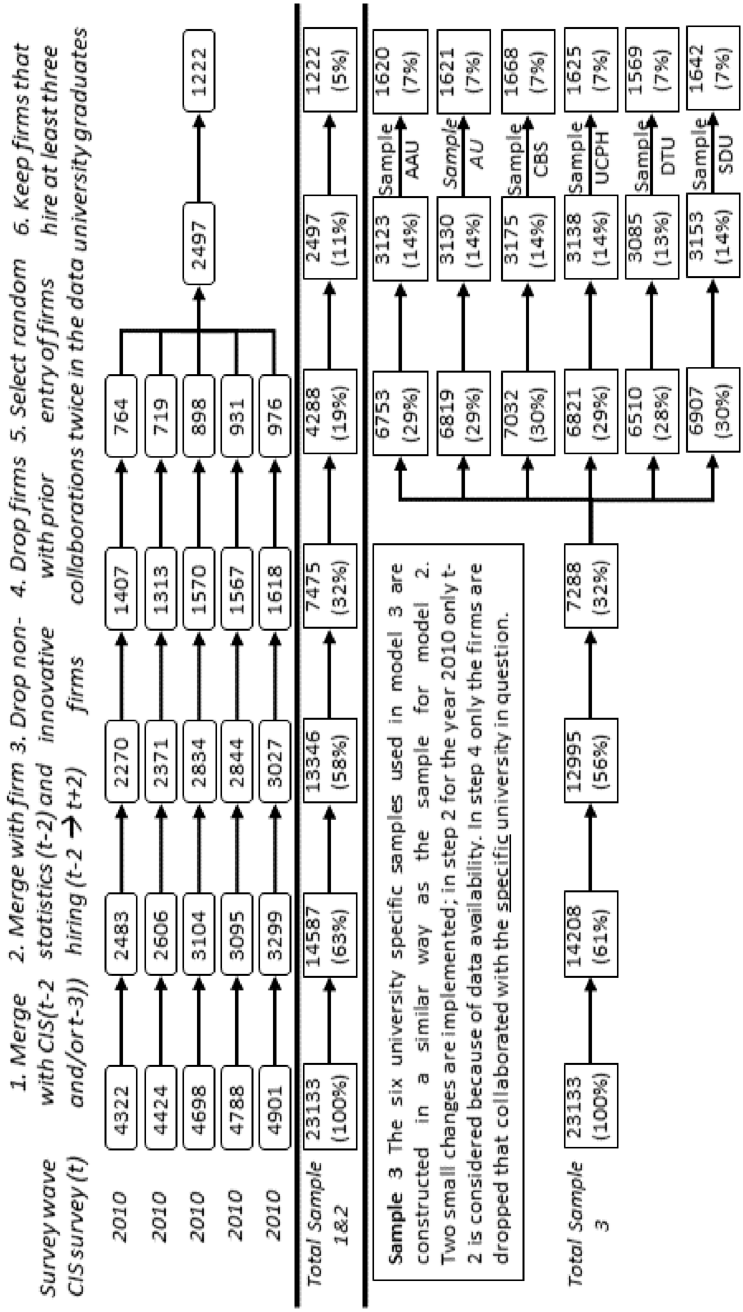
3.2 Data and sample

The primary data source used is the Danish version of the Community Innovation Survey (CIS). The sampling is done by Statistics Denmark via a two step process; in the initial step a population of over 10,000 firms in Denmark is selected. This population is composed of two groups of firms. First, all firms are included that had either more than 250 employees, a turnover of more than 1 billion Danish krones, reported R&D and innovation spending in previous surveys, or were part of the Research and Development sector. This group is complemented with a second group of firms that are selected using stratified sampling based on the number of employees and industry (Statistics Denmark, 2011). In the subsequent step approximately 4,500 firms from this population are invited to complete this survey. Firms are in this step sampled based on the number of Full-Time Equivalents (FTEs) and sector. All firms with more than 100 FTEs are included in the sample, and likeliness of being included in the sample increases with the number of FTEs and R&D intensity of the sector (Statistics Denmark, 2016). In the survey firms are asked about their innovation activities and collaborations in the two preceding years. The survey is available in Danish at the website of Statistics Denmark (n.d.). The survey is mandatory by law, which is enforced with reminders and eventual legal actions, resulting in very few non-responses (Statistics Denmark, 2011). A comprehensive validation of the data is carried out within the electronic questionnaire by a variety of checks within the survey, as well as triangulating some of the figures after completion of the survey (Statistics Denmark, 2016).

The survey data from time t is subsequently transformed in several steps to our final data frame (see also Figure D.1 on page 172). In the first the CIS of year t is merged with the CIS t-2 and/or CIS t-3 to get an indication whether the firm has been collaboration with the university before. Firms for whom no data is available for any of these years are dropped from the sample. In step 2 the dataset is merged with register data from the Integrated Database for Labor Market Research (IDA) provided by Statistics Denmark which provides data for some control variables as well as the hiring behaviour displayed by the firms in question over the timeframe t-2 till t+2. For the assessment of the hiring the workforce of two years after the survey is compared with the workforce two years prior to the survey. The margin of two years prior is picked since we do not know exactly in which year in the two year period prior to the survey the firm did collaborate, while the two years after margin is selected to capture also the hiring in the direct aftermath of the surveyed period. An individual is considered to be hired over this timeframe when they are not present in the prior workforce but do appear in the after workforce. In step three firms that report no R&D spending or collaboration on innovation in the survey are excluded from the sample to reduce the heterogeneity. In the next step, firms are dropped that have been collaborating with a university at t-2 and/or t-3. This is done, because insight needs to be obtained how collaboration changes the recruitment strategy of the firm in question, which is not possible if firms are already involved in these collaborations.

Subsequent, to increase the sample size, the annual survey waves of 2010, 2011, 2012, 2013 and 2014 are combined, and only one random entry is kept in case firms completed the survey multiple times. This results in a sample of 2497 firms for the first hypothesis. For hypothesis two only firms are assessed that hire at least three university graduates, as the target is to assess how firms that hire university graduates are also more likely to hire a PhD graduate, resulting in a sample of 1222 firms. For the third hypothesis six samples, one for each of the six largest universities in Denmark. The

Figure D.1: Sampling flowchart



difference compared to sample 2 is that in here firms that not all firms that collaborated with a university in the year prior are dropped, but only firms that collaborated with that particular university. This is done to maintain the sample size as much as possible. This does not introduce a bias since the ultimate interest in the analyses for hypothesis 3 is in detecting the effect of collaborating with a specific university.

3.3 Operationalisation and analysis

Owing to the possible endogeneity involved in a firm's decision to collaborate with a university, a quasi-experimental research design is used to measure the effect of the collaboration on the recruitment behaviour of the firms. For this purpose, we used the genetic matching method described by Diamond and Sekhon (2013), which is implemented in the R Matching package (Sekhon, 2011). The premise of the genetic matching is to use an algorithm to balance the covariates of a treatment group with the covariates of a control group. In some of the samples, outliers need to be eliminated to achieve this balance. After achieving balance on the covariates the average treatment effect on the treated can be assessed, which represents the absolute difference in the dependent variable between the treatment and control group.

For the first hypothesis needs to be assessed how firms start to focus on the hiring of university graduates when collaborating with a university. The dependent variable is measured in the following way:

$$share\ university\ graduates\ of\ new\ hirees = \frac{\text{number of university graduates among new hirees}}{number\ of\ new\ hirees}$$

In the subsequent matching model the treatment group consist of firms that indicated to have collaborated with a university on innovation. This is measured with the question that asks firms whether they in the two years preceding the survey have collaborated with universities on innovation. The control group is a group of firms with on average the same covariates—share of graduates in the workforce prior to the collaboration, logarithm of firm size in number of FTE, logarithm of firm age in years, and industrial grouping—but that did not collaborate with a university. Share of graduates might reflect an initial difference in the likelihood of firms for hiring graduates, larger firms are more likely to hire graduates (Belfield, 1999), younger firms started their recruiting in an era in which university graduates are more prevalent on the labour market which might induce an upwards bias in the first control (OECD, 2020), and some industries are more knowledge intensive or closer to academia (Sauermann & Stephan, 2013). The industry control is made using nine distinct groups of industries based on their knowledge-intensiveness (see Eurostat (n.d.) and Appendix A for the groupings made). Given the importance of the latter covariate, it is assured that the matching is exact on the industry grouping.

For the analysis of the second hypothesis, it is assessed whether firms that collaborate with a university are more likely to hire PhD graduates. For this purpose, a dummy is constructed that indicates whether a firm hired a PhD graduate or not. The choice for a dummy is partly made because hiring a PhD is a quite rare event and only represents a tiny fraction of the total recruitment of university graduates. In the subsequent matching model the treatment is the same as in model 1, being whether a firm indicated to have collaborated with a university on innovation in the survey. The same covariates as for hypothesis 1 are applied, but in addition we match on the share of PhD graduates among the university graduates in the workforce prior to the collaboration and a dummy indicating whether the firm already employed a PhD graduate prior to the collaboration. For the analysis of the third hypothesis it is assessed how firms refocus their hiring of university graduates to graduates trained by their university partner. The dependent variable is measured in the following way:

$$share\ university\ X\ of\ university\ graduates\ hired = \frac{\text{number of university X graduates among new hirees}}{number\ of\ university\ graduates\ among\ new\ hirees}$$

In this measurement only graduates trained in the main city of a university are considered; several of the universities included in this study have branch campuses in other cities in Denmark, but the limited size of these campuses restricts the impact of these campuses on the dynamics studied. Subsequently, for the six largest full universities in Denmark a matching model is constructed in which the treatment group consist of firms that indicated to have collaborated with that specific university on innovation. In addition to the balancing covariates for hypothesis 1, we balance the groups on the share of graduates from that specific university in the workforce prior to collaboration and the square root of the travel time in minutes from the firm to the university. The first is to control for that some firms are due to their specialisation already more likely to hire graduates from specific universities. The relevance of the travel time covariate stems from an initial preference by graduates to stay in the region of study and for firms to hire locally, while geographical proximity is also facilitating university-industry collaborations (Drejer & Østergaard, 2017).

4 Results

4.1 Empirical Context

Denmark hosts eight major full universities that are certified to award bachelor, master and PhD degrees (see Table D.2). Four of these universities are located within the capital region, while the others are evenly spread across the country. Five of the Danish universities cover all the major academic disciplines, while CBS is a business school and the Technical University of Denmark and the IT University of Denmark have a clear technical profile. Substantial size differences exist between the universities as reflected in the student numbers. The size and technical profile seem to correlate with the number of collaborations for each university reported by the technology transfer offices of the universities in 2014. The RUC and ITU host only a relatively small number of collaborations, which makes achieving balance in the sample a matter of concern, and therefore the study of the university-specific effects will be focused on the remaining six universities.

Table D.2: Overview universities 2014.

	Region	**Social sciences**	**Human-ities**	**STEM**	**Health**	**Total**	**Collabo-rations**
Aalborg University (AAU)	North	5,782	5,040	8,022	1,567	20,411	398
Aarhus University (AU)	Central	14,341	12,290	7,176	4,313	38,120	415
Copenhagen Business School(CBS)	Capital	15,461	2,216	0	0	17,677	57
University of Copen-hagen (UCPH)	Capital	11,147	12,297	9,539	7,899	40,822	365
Technical University of Denmark (DTU)	Capital	0	0	10,311	0	10,311	849
IT University of Den-mark (ITU)	Capital	0	0	1,915	0	1,915	11
Roskilde University (RUC)	Zealand	3,202	3,519	1,324	0	8,045	46
University of South-ern Denmark (SDU)	South	8,305	7,249	4,515	4,257	24,326	111

source: Danske Universiteter (2019) and Ministry of Higher Education and Research (n.d.)

4.2 Sample descriptives

Table D.3 provides descriptives of the firms in our sample distinguishing collaborating and non-collaborating firms. Collaborating firms have a larger share of university graduates in their workforce, are larger and older, and are more present in the more knowledge-intensive sectors. Given these significant initial differences between these groups, it would be naturally for the former group to hire more university graduates and not related to the collaboration itself. Therefore, assessing these differences requires us to apply a matching approach to compare the group of collaborating firms to a group of firms with similar characteristics. Table D.4 on page 177 list the resulting balanced samples. Eight distinct samples are shown; one for each of the first two hypotheses and one for each of the six universities assessed in the third hypothesis. The matching applied also results in the dropping of several observations for which no match can be found. No significant differences exist in the mean or distribution in any of the models between the covariates of the treatment and control group at the 0.05 level. In addition QQ-plots are inspected for anomalies. Table D.4 also give insight in some differences in the collaboration partners between universities, in which the industry background of the sample considered for the Copenhagen Business School is remarkably different from that of the other universities.

Table D.3: Descriptive statistics unmatched sample.

	Collaborating firms (n=652)		**Non-collaborating firms (n=1845)**	
	Mean	*SD*	*Mean*	*SD*
Share university graduates in workforce two year prior to survey	0.21	0.24	0.15	0.19
Log firm size(absolute firm size)	4.15	1.48	3.88	1.29
Log firm age(absolute firm age)	2.90	0.81	2.85	0.74
	Industry control dummies			
Primary sector	0.01		0.01	
Utilities	0.04		0.01	
Construction	0.02		0.03	
Low technology manufacturing	0.07		0.09	
Medium-Low technology manufacturing	0.06		0.08	
Medium-High technology manufacturing	0.10		0.08	
High technology manufacturing	0.05		0.03	
Knowledge-Intensive services	0.38		0.33	
Non-knowledge-intensive services	0.29		0.34	

4.3 Matching analysis

Figure D.2 and Table D.5 displays the estimates produced for the matched treatment and control groups. The results of model 1 for the testing of hypothesis 1 indicate that the share of university graduates among new employees is significantly 2.4 percentage points higher for firms collaborating with a university than for similar non-collaborating firms. This difference translates into a 13% higher proportion of university graduates hired by firms that are collaboration with a university. These findings confirm hypothesis 1.

The matching model for hypothesis two also indicates a significant difference between the treatment and control group, with firms that are collaborating 5.6 percentage points more likely to hire a PhD graduate. This translates

Table D.4: Balance results

	Model 1 Share university graduates		**Model 2 PhD dummy**		**Model 3 Share graduates university partner among university graduate hired**											
	General		*General*		*AAU*		*AU*		*CBS*		*UCPH*		*DTU*		*SDU*	
University-industry collaboration	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Share university graduates	0.21	0.21	0.24	0.23	0.26	0.25	0.33	0.3	0.33	0.31	0.33	0.37	0.23	0.25	0.31	0.3
Dummy PhD graduates prior	-	-	0.27	0.27	-	-	-	-	-	-	-	-	-	-	-	-
Share graduates collaboration partner in workforce	-	-	-	-	0.019	0.018	0.069	0.065	0.064	0.053	0.059	0.055	0.066	0.062	0.054	0.049
Square root (travel time to collaboration partner)	-	-	-	-	13	13.2	9.69	10.07	2.94	3.08	3.3	3.33	7.67	6.92	4.08	4.16
Log firm size	4.07	4.06	4.82	4.77	5.12	5.05	5.16	5.12	6.08	5.96	4.85	4.75	5	4.9	5.15	5.03
Log firm age	2.9	2.88	3.03	3	3.13	3.26	2.98	3.1	3.15	3.32	3	2.94	3.13	3.14	3.11	3.12
Primary sector	0	0	0.01	0.01	0.03	0.03	0	0	0	0	0.02	0.02	0	0	0	0
High technology manufacturing	0.04	0.04	0.05	0.05	0.13	0.13	0.04	0.04	0.00	0.00	0.06	0.06	0.07	0.07	0.05	0.05
Medium-high manufacturing	0.10	0.10	0.10	0.10	0.13	0.13	0.18	0.18	0.03	0.03	0.15	0.15	0.15	0.15	0.2	0.2
Medium-low manufacturing	0.06	0.06	0.05	0.05	0.11	0.11	0.09	0.09	0.08	0.08	0.02	0.02	0.11	0.11	0.05	0.05
Low technology manufacturing	0.07	0.07	0.06	0.06	0.10	0.10	0.14	0.14	0.03	0.03	0.13	0.13	0.15	0.15	0.09	0.09
Knowledge intensive services	0.39	0.39	0.38	0.38	0.29	0.29	0.39	0.39	0.51	0.51	0.51	0.51	0.26	0.26	0.43	0.43
Low-knowledge intensive services	0.3	0.3	0.28	0.28	0.17	0.17	0.13	0.13	0.27	0.27	0.06	0.06	0.17	0.17	0.11	0.11
Utilities	0.03	0.03	0.04	0.04	0.03	0.03	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.06	0.06
Construction	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.03	0.03	0.00	0.00	0.04	0.04	0.02	0.02

Table D.5: Matching results

	Model 1: Share of university graduates among new hirees	Model 2 Hiring a PhD graduate	Model 3: Share of graduates from university partner among university graduates hired					
General	*General*	*General*	*AAU*	*AU*	*CBS*	*UCPH*	*DTU*	*SDU*
Number of matches	615	372	63	56	37	47	72	65
Absolute estimate	0.024	0.056	0.098	0.000	0.050	0.083	0.076	0.017
Standard error	0.009	0.026	0.021	0.024	0.031	0.021	0.026	0.026
Relative estimate (treatment/control)	1.13	1.32	2.17	1.00	1.28	1.66	1.39	1.09
P-value	0.007	0.030	0.000	0.968	0.1096	0.000	0.004	0.507

to a 32% difference between the treated and control group and confirms hypothesis 2.

The six matching models for the testing of hypothesis 3 deliver similar results, indicating a substantial increase in the share of graduates trained by the university with whom the firm is collaborating among the total number of graduates hired by the firm. However, these findings are only significant for Aalborg University, the University of Copenhagen and the Technological University of Denmark. Therefore we can partly accept hypothesis 3.

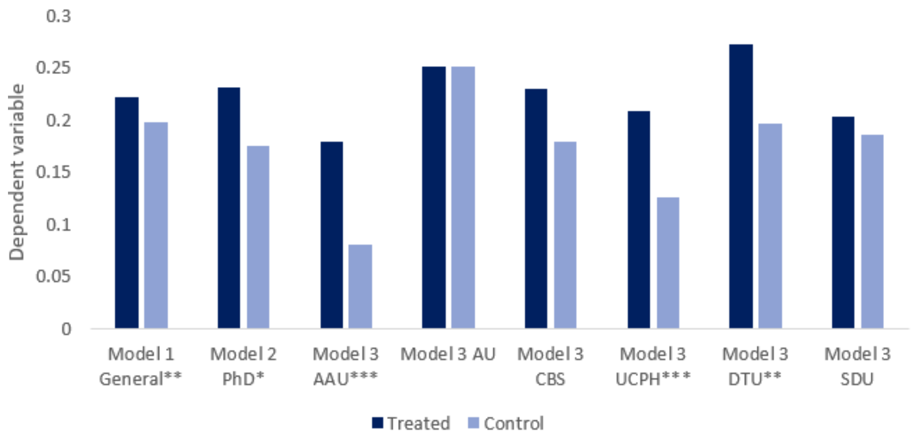


Figure D.2: Differences in dependent variables between treated and control group.
Note: Statistical significance *=0.05, **=0.01, ***=0.00

5 Discussion and conclusion

Firms can use university-industry collaborations as a way to strengthen their knowledge base by knowledge transferred from university to their firm. Yet, cultural distance, limited absorptive capacity, tacitness of the knowledge and absence of social capital can undermine possible university-industry knowledge transfer and thereby inhibit firms from capturing these benefits of the collaboration. This paper analysed the hiring of university graduate as an applied strategy by firms to address these barriers to knowledge transfer.

Using genetic matching to address the endogeneitiy, the analysis has shown that firms collaborating with a university hire 13% more graduates than similar firms that do not collaborate with a university. The hiring of university graduates could be part of what Scandura (2016) describes as the increased investments in R&D and expansion of R&D departments following a university-industry collaboration. By attracting these graduates, firms position them better for overcoming the absorptive capacity and cultural barrier to which Bruneel et al. (2010) point as barriers for successful university-industry knowledge transfer. The additional finding that these firms are also more likely to be involved in the recruitment of PhD graduates, is in line with the findings of Lim (2009) and signifies that these graduates might be able to offer additional value in this context. Furthermore, firms tend to focus their hiring of graduates on graduates trained by their university partner, providing them with social capital and tacit knowledge that could facilitate the knowledge transfer across organisational boundaries. Yet this effect is only significant for three of the six universities. A possible explanation for this may be found in the fact that these universities have a stronger STEM and health sciences profile, which could lead to collaborations in which the hiring of graduates from the collaboration partner turns out to be more important than is the case in collaborations with a humanities or social sciences character. However, the current analysis does not provide enough evidence for doing any statements on whether this might be part of the explanation, and further research into this is highly recommended. The size of the university specific effect is substantial, and accounts for a major part of the effect on the hiring of university graduates that was observed in hypothesis 1. Nevertheless, the data suggests that there is still also a growth in the hiring of graduates trained by universities other than the collaboration partner.

The findings indicate that firms who are collaborating with a university are investing in expanding their absorptive capacity by hiring more university graduates. This fuels a further divergence, as the firms that are collaborating with a university, already, tend to have a larger share of university graduates in their workforce (see e.g. Table D.3). In turn, this positions them better for further collaborations, which again could boost their hiring of university graduates. However, it could be argued that decreasing returns on an additional increase in the share of graduates would prevent these dynamics. Further research could provide insight into this.

Although the used quantitative data allows identifying these differences in the recruitment of new employees, it is not possible to assess the underlying motivations for this changed hiring behaviour. It could even be argued that the results reflect partly an omitted variable, such as a change of firm strategy aimed at increasing the knowledge intensity of the firm, that incorporates both collaborating with universities and the hiring of graduates as independent parts of such a strategy. However, it is deemed unlikely that these decisions are really independent parts of such a strategy. Especially considering the focus of firms to increase the hiring of graduates specific from their collaborating partner suggest that the observed hiring behaviour is likely to be related to the university-industry collaborating in which the firm is involved. Nevertheless, the literature could benefit from further in-depth studies into these dynamics in understanding why firms change their hiring behaviour when collaborating with universities. This could be combined with a further exploration of the differences in collaboration dynamics between technological oriented universities and universities with a stronger social sciences and humanities profile. While this study provided empirical evidence for the existence of the general and university-specific hiring effect, we did not take into consideration how this influences the nature and other outcomes of the collaboration. Our argument assumes that by enabling a smoother university-industry knowledge transfer, firms will benefit in the end. However, further research could shed further light on this.

The main contribution of this paper is that it showed the permanent transformative powers of a university-industry collaboration; by altering the hiring dynamics, university-industry collaborations have a significant long-term impact on the composition of the firm's workforce, which will have an impact in a time window that is beyond the collaboration with the university. In this time window, the acquired graduates might as Drejer and Østergaard (2017) showed act as seeds from which new university-industry collaborations emerge. Therefore, we argue for a more prominent position of hiring as a success measure for evaluating the success of university-industry collaborations.

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A Industry groupings

Table D.6: Industry groupings.

Industry aggregations	**NACE Rev.2 branch codes**
1. Primary sector	(01) Crop and animal production, hunting and related service activities; (02) forestry and logging; (03) fishing and aquaculture; (05) mining of coal and lignite; (06) extraction of crude petroleum and natural gas; (07) mining of metal ores; (08) other mining and quarrying; (09) mining support service activities
2. Utilities	(35) Electricity, gas, steam and air conditioning supply; (36) water collection, treatment and supply; (37) sewerage; (38) waste collection, treatment and disposal activities; materials recovery; (39) remediation activities and other waste management services
3. Construction	(41) Construction of buildings; (42) civil engineering; (43) specialised construction activities
4. Low technology manufacturing	(10) Manufacture of food products; (11) manufacture of beverages; (12) manufacture of tobacco products; (13) manufacture of textiles; (14) manufacture of wearing apparel, except fur apparel; (15) manufacture of leather and related products; (16) manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials; (17) manufacture of paper and paper products; (18) printing and reproduction of recorded media; (31) manufacture of furniture; (32) other manufacturing
5. Medium-Low technology manufacturing	(19) Manufacture of coke and refined petroleum products; (22) manufacture of rubber and plastic products; (23) manufacture of other non-metallic mineral products; (24) manufacture of basic metals; (25) manufacture of fabricated metal products, except machinery and equipment; (33) repair and installation of machinery and equipment
6. Medium-High technology manufacturing	(20) Manufacture of chemicals and chemical products; (27) manufacture of electrical equipment; (28) manufacture of machinery and equipment; (29) manufacture of motor vehicles, trailers and semi-trailers; (30) manufacture of other transport equipment

Continuation of Table D.6

Industry aggregations	**NACE Rev.2 branch codes**
7. High technology manufacturing	(21) Manufacture of basic pharmaceutical products and pharmaceutical preparations; (26) manufacture of computer, electronic and optical products
8. Knowledge-Intensive services	(50) Water transport; (51) air transport; (58) publishing activities; (59) motion picture, video and television programme production, sound recording and music publishing activities; (60) programming and broadcasting activities; (61) telecommunications; (62) computer programming, consultancy and related activities; (63) information service activities; (64) financial service activities, except insurance and pension funding; (65) insurance, reinsurance and pension funding, except compulsory social security; (66) activities auxiliary to financial services and insurance activities; (69) legal and accounting activities; (70) activities of head offices and management consultancy activities; (71) architectural and engineering activities and technical testing and analysis; (72) scientific research and development; (73) advertising and market research; (74) other professional, scientific and technical activities; (75) veterinary activities; (78) employment activities; (80) security and investigation activities; (84) public administration and defence and compulsory social security; (85) education; (86) human health activities; (87) residential care activities; (88) social work activities without accommodation; (90) creative, arts and entertainment activities; (91) libraries, archives, museums and other cultural activities; (92) gambling and betting activities; (93) sports activities and amusement and recreation activities

Continuation of Table D.6

Industry aggregations	**NACE Rev.2 branch codes**
9. Non-knowledge-intensive services	(45) Wholesale and retail trade and repair of motor vehicles and motorcycles; (46) wholesale trade, except for motor vehicles and motorcycles; (47) retail trade, except for motor vehicles and motorcycles; (49) land transport and transport via pipelines; (52) warehousing and support activities for transportation; (53) postal and courier activities; (55) accommodation; (56) food and beverage service activities; (68) real estate activities; (77) rental and leasing activities; (79) travel agency, tour operator reservation service and related activities; (81) services to buildings and landscape activities; (82) office administrative, office support and other business support activities; (94) activities of membership organisations; (95) repair of computers and personal and household goods; (96) other personal service activities; (97) activities of households as employers of domestic personnel; (98) undifferentiated goods- and services-producing activities of private households for own use; (99) activities of extraterritorial organisations and bodies

Part IV

Further insights in university-industry knowledge transfer channels

Paper E

Knowledge sharing in smart grid pilot projects

Gerwin Evers and Maryse M.H. Chappin

The paper is currently under review

The layout has been revised.

Abstract

The major role that the electrification of the energy system is projected to play in the transition to a sustainable economy increases the pressure on the electricity grid and thereby creates a demand for the implementation of smart grid technologies. The interdependencies present in the electricity system require, and have led to, the wide-scale adoption of pilot projects to develop knowledge about the application of these technologies. While the knowledge sharing that stems from these projects is one of the justifications for subsidising these projects, it has remained largely a black box. Based on the analysis of interviews with the project leaders of sixteen smart grid pilot projects, complementary secondary data sources and a survey, we studied knowledge sharing at four levels: intra-organisational, intra-project, inter-project and project-external knowledge sharing. At each level we observed specific sublevels, mechanisms and barriers, resulting in complex knowledge sharing dynamics. While the projects succeeded in developing knowledge, knowledge sharing between projects run by different consortium partners rarely occurred and project-external knowledge sharing was primarily unidirectional and involved generic knowledge. Based on the results a set of recommendations was developed that can stimulate the knowledge sharing and thereby increase the value generated by these projects.

Preface

Data collection for this paper was conducted during a research internship at the Netherlands Enterprise Agency from February to August 2016. These data were also used to write my master's thesis, and my initial idea was to submit an updated version of my master thesis to a journal. Along with Maryse M.H. Chappin, who was my supervisor during my master's thesis, I began updating the paper in 2018. While the core findings remained valid, we decided during this process to adapt the focus of the paper to better relate to ongoing discussions in the field. Revising this paper then took considerable effort and it is currently under review. Since this paper touches on issues that are relevant to the content of the dissertation, it was included here.

1 Introduction

The electrification of transportation and the incorporation of electricity from renewable sources into the energy mix is increasing the pressure on electricity distribution grids (Dyke et al., 2010). The implementation of smart grid technologies, also known as smart energy systems, has been projected to play a pivotal role in enabling the grid to cope with these new challenges (Coll-Mayor et al., 2007). However, the current electricity system is characterised by difficulties arising from interactions between a heterogeneous set of demand- and supply-side actors in a distinctive regulatory and market context. This system not only poses pure technological challenges, but also relies on interdependencies between system components (Markard & Truffer, 2006), which hinders even the small-scale application of innovations, such as smart grid innovations. To overcome this challenge, actors need to collectively develop and share knowledge and innovations, what for smart grid innovations often happens in pilot projects (de Reuver et al., 2016; Planko et al., 2017, 2019).

Pilot projects are used to experiment with and demonstrate new technologies in a relatively protected environment (Billé, 2010; Turner & Müller, 2003). A pilot project typically takes place on a small scale and aims to develop knowledge about the new technology as well as to create insight into how the new technology will fit into society (Markusson et al., 2011). The knowledge developed during the pilot project, consisting of both experience and expert insights, is of strategic importance for other actors facing similar issues (Davenport & Prusak, 1998). The idea behind the use of pilot projects is that when they are successful, the project can be followed by a scale-up and a large-scale implementation of a new technology. The sharing of the acquired knowledge with other actors in the sector should enable this larger-scale implementation of the piloted technologies. While this sharing might be deliberate in some cases, unintended spillovers are inevitable, generating additional returns that are not captured by the investing actors (Breschi & Lissoni, 2001), resulting in a market failure. This market failure of underinvestment in knowledge development resulting from public returns outweighing private returns (Martin & Scott, 2000) has been addressed through the provision of public funding to consortia for the execution of pilot projects (Klette et al., 2000). Even though governmental funding programmes typically aim to realise knowledge sharing, they often lack a clear notion of what kind of knowledge spillovers they aim for and how they should occur. Furthermore, it is also not always required to include a section on knowledge sharing in the project application, leaving knowledge sharing largely a black box. Therefore, it could be anticipated that knowledge sharing, despite its importance, receives little priority in demonstration projects (Hart, 2018).

The lack of understanding knowledge sharing dynamics is not surprising given the complexity of knowledge sharing as a concept. Knowledge sharing might entail recombining the knowledge of multiple partners or exchanging or disseminating knowledge (Nahapiet & Ghoshal, 1998). In the context of this study, actors in pilot projects can share different kinds of knowledge (Hau et al., 2013) via several mechanisms (McDermott & O'Dell, 2001) while being constrained by a variety of barriers (Riege, 2005). The literature on knowledge sharing, however, does not systematically discuss this. Understanding this process is critical, since lack of knowledge is a bottleneck for the further development of smart grids (Muench et al., 2014), and knowledge sharing could pave the way for further large-scale implementations of piloted technologies (Nemet et al., 2018). In this paper, we aim to differentiate between intra-organisational, intra-project, inter-project and project-external as four distinct levels of knowledge sharing in pilot projects. At each of these levels, different mechanisms and barriers to knowledge sharing are at play. We aim to provide insight into the knowledge sharing dynamics present at these four levels.

Considering the limited existing knowledge on these dynamics, an explorative approach was adopted in which the project leaders of sixteen smart grid pilot projects in The Netherlands funded by the Netherlands Enterprise Agency (RVO.nl) were interviewed. These interviews provided insight into the knowledge sharing dynamics at these four different levels of knowledge sharing. The findings show that at all these levels, a variety of mechanisms and barriers play a role in explaining the knowledge sharing. It is remarkable that inter-project knowledge sharing with unconnected projects (that do not have project partners in common) rarely occurs. Moreover, project-external sharing is primarily unidirectional and involves only generic knowledge. By providing insight into these areas, this research contributes to the literature on knowledge sharing in general and to the literature on knowledge sharing of pilot projects in particular. The findings enable policymakers, both inside and outside the energy sector, to develop deliberate knowledge sharing policies to facilitate the sharing of knowledge developed in government-funded pilot projects. This paper provides a review of the literature on knowledge sharing at the four identified levels, followed by an explanation of the methods and data and a combined results–discussion section. The paper ends with concluding remarks and policy recommendations.

2 Literature review

2.1 Knowledge sharing

Knowledge sharing refers to the process by which knowledge is exchanged between two or more actors (Sharratt & Usoro, 2003). This knowledge can be codified or tacit. Codified knowledge is knowledge that can be formally articulated and written down, whereas tacit knowledge consists of experiences, routines and developed skills which are stored in people and processes (Polanyi, 1966).Tacit knowledge is understood to provide organisations the foundation for a sustainable competitive advantage, since it is difficult to articulate, to write down and to copy (Cavusgil et al., 2003; Zack, 1999). Another distinction that can be made is between generic and specific knowledge. Generic knowledge is the knowledge that forms the basis of most products and services in a specific sector (Pemberton & Stonehouse, 2000), whereas (organisation-)specific knowledge is the knowledge that allows organisations to deliver products or services that have an edge over those of its competitors, and it is thereby part of the organisation's core competencies (Stonehouse & Pemberton, 1999).

We differentiate between four different levels at which knowledge sharing can be observed in pilot projects: intra-organisational, intra-project, inter-project and project-external. Literature (e.g. Easterby-Smith et al. (2008)) has shown that there are differences between intra-organisational (level 1) and inter-organisational (levels 2-4) knowledge sharing because boundaries are different. This is also the case for our set of levels and this will impact upon the success of knowledge sharing, upon what can and will be shared at these four levels as well as the specific barriers.

For intra-organizational as well as for inter-organizational knowledge sharing, scholars have looked into factors that enable or hinder knowledge sharing, which have been categorised for instance into individual, organizational and technological factors (see for instance the literature review of Riege (2005) and the conceptual paper of Nooshinfard and Nemati-Anaraki (2014)).

For the pilot project setting, however, we distinguish more levels and the literature has not yet discussed the knowledge sharing at all our four specific levels. For each of these different levels we will explain what, based on the available literature, we expect the benefits are of successful knowledge sharing, and what kind of knowledge will be shared as well as what barriers can be expected.

2.2 Knowledge sharing at different levels

2.2.1 Intra-organisational knowledge sharing

Organisations, which can be seen as collections of individuals that share particular objectives, can benefit from intra-organisational knowledge sharing as it helps to achieve these objectives (Ipe, 2003). Typically, only a fraction of the organisation's members are directly involved in a pilot project, while the relevant organisational expertise and knowledge is likely to be spread wider among other colleagues, urging the organisation's members involved in the project to draw on the knowledge of their colleagues for the execution of the project. Similarly, the relevance of the knowledge generated in the pilot project for the organisation and its members inform the decision to participate in such a pilot project. Hence, successful sharing of project knowledge increases the benefits that organisations can gain from their participation.

The intra-organisational setting facilitates frequent interactions, which offers the organisation's members a context that is conducive for the sharing of tacit knowledge (Zack, 1999). This setting is also likely to have limited competition concerns about sharing specific knowledge.

Possible barriers are formal hierarchical structures, power dynamics and costs. The formal hierarchical structures can hinder the informal social interactions between departments that play a crucial role in knowledge sharing (Tsai, 2002). Power dynamics between subsidiaries in multinational companies can influence the knowledge sharing between subsidiaries (Birkinshaw & Hood, 1998). Furthermore, the employee-level costs involved in sharing knowledge with colleagues creates an intra-organisational version of the knowledge as a public good dilemma. Resolving this requires organisational incentives and culture that enables intra-organisational knowledge sharing (Cabrera & Cabrera, 2002).

2.2.2 Intra-project knowledge sharing

The increasing complexity of knowledge-intensive sectors and the reality that expertise is distributed across organisations requires organisations to become involved in collaborative knowledge development processes (Powell et al., 1996), such as pilot projects. Therefore pilot projects are usually executed by consortia of organisations with varied sectoral and institutional backgrounds. This offers the consortia access to non-overlapping, complementary knowledge bases (Sakakibara, 2003), while at the same time reducing the risk of opportunistic behaviour due to the absence of competitors (Doz et al., 2000). Thus, successful knowledge sharing within the project increases the benefits of the project and the project partners involved.

Intra-project knowledge sharing within these consortia takes place to enable the combination of different knowledge bases (Nahapiet & Ghoshal, 1998). In order to be successful also tacit and specific knowledge needs to be shared.

Possible barriers are related to coordination costs and the unwillingness to share tacit knowledge, Although including more partners can further extend the knowledge base (Liebowitz & Suen, 2000), coordination costs are likely to outweigh these advantages (Camacho, 1991). In order to have successful intra-project knowledge sharing, the sharing of some specific tacit knowledge will be required. This is not necessarily something organizations are keen to do. However, it is likely that they do not necessarily need to open their entire knowledge base to their partners, but instead limit their access to the extent that is needed for the execution of the project.

2.2.3 Inter-project knowledge sharing

Pilot projects are usually part of larger, topic-defined programmes, and meanwhile, international, national and regional funding programmes might be funding similar projects. These projects are likely to encounter similar challenges, and the consortia might learn from each other's solutions (Kasvi et al., 2003), possibly in a reciprocal way (Bock et al., 2005). This is what we label knowledge sharing at the inter-project level. Successful knowledge sharing between projects might realize synergies for the consortia, yet are also likely to generate social returns through knowledge spillovers.

Inter-project knowledge sharing takes place to learn from other projects how to address particular challenges. Therefore the knowledge is likely to be context-specific.

A possible barrier is the unwillingness to share knowledge with other projects because it is unclear how the project will benefit from it. Moreover, the sharing of the specific knowledge might require intensive collaboration, and therefore investments in time, to facilitate the exchange of knowledge between the projects.

2.2.4 Project-external knowledge sharing

The final level is project-external knowledge sharing. Successful knowledge sharing with external parties will mainly create social returns. It could however also result in some private benefits. For universities and research organisations it is the default to disseminate the knowledge to their respective communities. While the majority of their readers is from within the academic community, scientific articles are still considered one of the most important channels through which university knowledge reaches industry (Bekkers & Bodas Freitas, 2008). Also the increased citation of scientific articles in industry patents suggests a readership in industry circles (Narin et al., 1997). Furthermore, the rising trend of open access publishing (Laakso et al., 2011) is also understood to contribute to the dissemination of research outside the academic community (Davis, 2011). Other project partners might share knowledge to further the transition from which they will benefit (Van de Ven, 2005), while some partners use it to strategically influence policy (Austen-Smith, 1993).

Given that project-external knowledge sharing is about external dissemination of project knowledge it is most likely to be codified and general.

Barriers to project-external knowledge sharing are a lack of financial and human resources. However, the external dissemination of the knowledge developed in the pilot project is usually obligatory upon receiving public funding. Nowadays, most funding bodies require projects to include a strategy in the project plan describing how the project knowledge will be made available to external actors, often complemented with a set of compulsory project deliverables (European Commission, n.d.). Including a knowledge dissemination strategy allows projects to reserve resources, both in funding and time, to invest in these dissemination activities.

A concrete model of knowledge sharing for our four levels is missing in the literature. Therefore, we aim to unravel the knowledge sharing dynamics present at these different levels by exploring for each of the levels the different mechanisms through which knowledge sharing takes place as well as the barriers.

3 Methodology and data

3.1 Research design and empirical context

The study uses a qualitative research approach, focussed on Dutch smart grid pilot projects, to further our understanding of how the knowledge developed in pilot projects is shared. Since the early 2010s RVO.nl has executed several smart grid subsidy programmes, including the Innovation Programme Smart Grids (IPIN), which ran from 2011–2016 and funded twelve pilot projects, followed in 2012 by similar programmes which funded fifty pilot projects through the Top Consortium for Knowledge and Innovation (TKI) Switch2Smartgrids (and its successors). Public-private consortia can submit a project proposal and compete for a subsidy within these programmes. At the time of the data collection (spring 2016), the majority of the TKI Switch2Smartgrids programme projects had just begun, which made them unsuitable to include in our study. From the twenty-five pilot projects that were suitable for our study, seventeen accepted the interview invitation. The main reason for non-participation was time constraints. Subsequently, one project was excluded from further analysis when it turned out during the interview that the pilot project was due to some delays still in a too premature phase, resulting in a final sample of sixteen projects.

3.2 Data collection

For each pilot project, data were collected through desk research and semi-structured interviews. The desk research preceding the interviews, which employed both internal RVO.nl internal and publicly available data, provided a general understanding of the technical nature of the projects as well as familiarity with the different actors in the smart grid sector. This facilitated an atmosphere during the interviews in which the project leaders were comfortable sharing in-depth insights about the knowledge sharing of their respective projects. Moreover, for each project the knowledge sharing sections of the final project report have been studied.

We conducted the one-hour, semi-structured interviews with the project leaders, assuming that they are the most informed team members regarding the strategic and general developments within their projects, although realising that the insights into intra-organisational knowledge sharing of other consortium partners would therefore be limited. On two occasions an additional project member joined the interview. Providing anonymity and conducting the interviews in Dutch (the native language of the project leaders) allowed the project leaders to talk without constraints.

To complete the picture of the context and background of the projects, the project leaders were first asked about the functioning of their project, the collaboration within their consortium, and the role they fulfilled within the project. Subsequently, the project leaders were asked about how they defined knowledge; this was done to ensure that the interviewee and interviewer shared a similar understanding of this core concept. Next, we asked the interviewees what they meant by 'knowledge sharing' with regard to their project, which often resulted in elaborate answers which addressed all the four levels of knowledge sharing discussed in the literature review. The questions that followed zoomed in on inter-project and project-external knowledge sharing by asking to what extent such knowledge sharing occurred, in what ways, with whom, why and more. At the end of each interview, the role of RVO.nl in the sector was discussed, and the interviewees were offered the opportunity to discuss any additional topic they considered to be relevant.

In addition, a survey was conducted to capture the perspective of external actors on the receiving end of project-external knowledge sharing. The main topics covered in the survey were the demand for knowledge about smart grids, the applied knowledge search strategies and the specifics of potential interactions with the pilot projects covered in this study. The sample for the survey was drawn via a web search and the scraping of overview websites, sampling organisations similar to the project participants, but who were not participating in one of the subsidy programmes. The list of organisations was subsequently discussed with field experts to ensure that these organisations belonged to the target audience for project-external knowledge sharing, resulting in a final list of one hundred organisations. These organisations were approached and reminded to participate in the survey; ultimately, 30% completed the survey. Field experts indicated this percentage to be a good response rate, and since there were no clear biases in the non-response, the results can provide general insight into the demand-side of project-external knowledge sharing.

Additionally, during the time of the data collection, one of the authors participated in conferences and meetings intended for actors in the Dutch smart grid domain. Participation in these events not only offered a deeper understanding of the sector, but also enabled informal discussions about knowledge sharing dynamics with various stakeholders. When these stakeholders or one of the interviewees mentioned interesting developments, further desk research or discussions with stakeholders were initiated.

3.3 Data analysis

The analysis consisted of three steps. First, using NVivo we distinguished the sections covering the different knowledge sharing levels in the interview transcripts. We then coded the mechanisms and barriers present at each level, which also lead to the identification of the sublevels. Second, for each level we examined the statements made by the project leaders to obtain holistic coverage of the level. Subsequently, we zoomed in onto the sublevels and its mechanisms, as well as the barriers present at the level. In the final steps the resulting analysis was complemented with the survey data and data from the knowledge sharing sections of the final project reports, either as additional insights or as context for the interview findings.

In writing-up the research, the interview quotes were anonymised, translated to English and used to support our findings. Anonymous letter codes were used to refer to the interviewees. Square brackets indicate clarification additions or anonymisation edits in the quotes.

Finally, to validate and contextualise our findings and policy recommendations, a previous version of this paper was discussed with a group of policy officers. Our results were considered to be relevant by them, and no radical or surprising additions were made following the discussion.

4 Results

4.1 Background information on the pilot projects

The scope of the pilot projects (hereafter referred to as 'projects') asked for such broad expertise that the median consortium size was six partners, including organisations from multiple sectoral and institutional backgrounds. During the formation stage, most consortia aimed to cover all the areas of expertise required for the execution of the project. This resulted in the participation of an electricity distribution company in most of the projects. Since the liberalisation of the Dutch electricity market, these government-owned companies have been responsible for maintaining and upgrading the grid in their area, making them key players in both enabling and benefitting from the smart grid innovations developed in these projects. However, also their vast financial resources made these actors attractive as consortium partner:

> Many actors see [distribution company] as a big bag of money with whom everyone therefore wants to collaborate.
>
> (Project leader M)

Other project participants came from the private domain (e.g. multinationals and SMEs), knowledge institutes (e.g. universities and research organisations), and the public domain (e.g. municipalities and cooperatives). On average, the projects received approximately 700,000 euros in subsidies, which covered 43% of the total project budgets on average, and ran with a mean duration of 38 months.

4.2 Knowledge sharing strategies

While the project plans were explicit about the technical objectives, most lacked a deliberate knowledge sharing strategy. Some project leaders were well aware of the knowledge sharing sections included in Horizon 2020 applications but did not include such a section in their own applications because it was not required by RVO.nl at that time. The presence of a section on knowledge sharing or an overview of publications in eleven final project reports indicates that throughout the duration of the programmes, RVO.nl has placed greater emphasis on the importance of knowledge sharing.

There were some projects in which there was someone responsible for external communication, and/or knowledge dissemination was (part of) a work package. However, the absence of a deliberate strategy meant that often no specific financial or human resources were reserved for knowledge sharing. There were quite some differences between project leaders in how they handled this situation. While some indicated that knowledge sharing should be a general task for all consortium partners without someone carrying the final responsibility, other project leaders assumed that it was one of their responsibilities.

A few project leaders adopted a proactive role in sharing knowledge, while others were more passive and waited until people came to them with requests. This might partially be explained by the personal characteristics of the project leaders; in general, those with a management background were more interested in interacting and sharing, while those with a technical background tended to be more interested in the execution of their project, and they thought less about the other aspects of the project. Another explanation might lie in the incentives for knowledge sharing present in the project leader's organisation: project leaders working for organisations that were destined to benefit from the large-scale adoption of smart grids, or the sharing of knowledge in general, were more engaged in sharing.

4.3 Knowledge sharing at different levels

This section zooms in on intra-organisational, intra-project, inter-project and project-external knowledge sharing. The dynamics at these levels are addressed by discussing the sublevels, the mechanisms and the barriers present at each level.

4.3.1 Intra-organisational knowledge sharing

Several project leaders mentioned the organisational level as an important level to share knowledge from the project:

> I am sometimes more occupied with telling about our project within our organisation than that I am doing so externally.
>
> (Project leader R)

At the intra-organisational level, three sublevels were identified at which knowledge sharing took place (see Figure E.1). We identified knowledge sharing within the local branch (Sublevel 1.1), knowledge sharing with other national branches (Sublevel 1.2) and knowledge sharing with foreign branches (Sublevel 1.3).

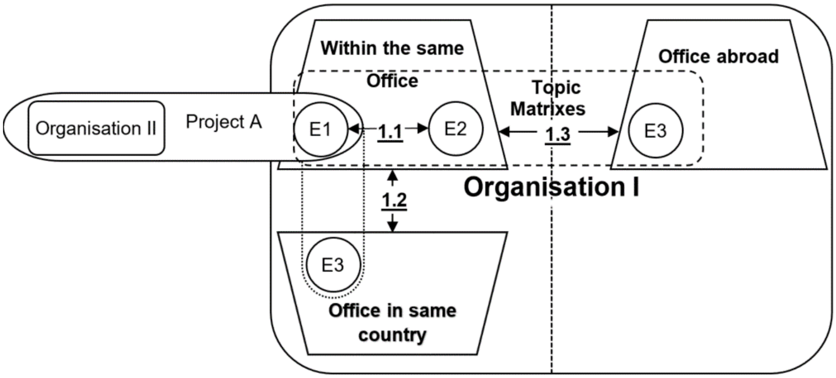

Figure E.1: Sublevels for intra-organisational knowledge sharing

The first intra-organisational sublevel was knowledge sharing with colleagues at the same geographical location (Sublevel 1.1). This meant not only disseminating knowledge internally, but also drawing on the available expertise. As Project Leader L noted,

> We are really technical, and the core [of the project] is ICT, and we have an entire department that always can help us.
>
> (Project leader L)

While the leader of Project L referred to this as simply asking for advice from colleagues, in Project K *"another colleague was included in the project than originally planned"*. Although intra-organisational knowledge sharing was prevalent in many organisations, smaller organisations were by default limited in the extent to which this could take place.

Second, several larger organisations also created a setting in which knowledge could be shared with colleagues of offices located elsewhere in the country (Sublevel 1.2). This sharing was often done on an informal basis: people knew each other on a first-name basis, and when in need of knowledge, these colleagues could be contacted with little effort. According to Project Leader L, when data on future energy prices was needed, *"One connection, and I have all the prices."* For Project Leader R this was not limited to a *"mouth-watering"* interest in knowledge available at other national branches: this project leader also tried to influence the direction of the research at another branch:

> We try to influence their research in a way that it really helps us. Those batteries, we can really benefit from that, we can make progress on this topic (. . .) we have contact about it.
>
> (Project Leader R)

In other instances, colleagues from different branches were together involved in a project, which facilitated the joint development and exchange of knowledge.

Third, multinational companies, in addition, enabled knowledge sharing with their colleagues abroad (Sublevel 1.3). Part of this knowledge sharing took place through formalised matrix structures in which employees working on similar topics met regularly to discuss recent developments:

> We have so-called matrixes (. . .) I am part of the green mobility programme (. . .) We exchange between all countries what we are doing and the progress is, in order to not replicate knowledge that is already developed abroad and vice versa.
>
> (Project Leader R)

Participation in pilot projects offered the local branches prestige within the larger organisation and allowed them to take the lead on topics:

> We as the Netherlands really take the lead; everything related to e-mobility is then also done in the Netherlands (. . .) Other people look to our project to see what they can learn from it
>
> (Project Leader R)

. On other occasions interactions with colleagues abroad enabled the re-use of knowledge, where in some cases the context was more favourable to particular smart grid applications, such as regions that are more vulnerable to blackouts. The strong knowledge base of the larger multinational companies allowed project participants to search internally for the necessary expertise to meet the challenges that could not be solved by the people directly involved in the project.

There was one recurring barrier to intra-organisational knowledge sharing: a lack of awareness of the knowledge and relevant colleagues within the organisation. Project Leader B, employed by a university that was involved in several projects, had little knowledge about other similar projects in which the university was participating:

> I have not heard too much about that project (...) But you do not know what you do not know until you do. (Project Leader B)

This lack of connection between different parts of the organisation was the case not only for the universities, but also for the multinational partners. Project Leader E, who was employed by a multinational company, expressed similar feelings:

> You should not overestimate how close we are connected as a multinational company; we are still really a national organisation. (Project Leader E)

4.3.2 Intra-project knowledge sharing

Most consortia had a contract and guidelines for intra-project knowledge sharing, specifying, among other issues, how to treat each other's intellectual property. Furthermore, direct competitors were excluded during the formation of the consortia: *"There were no partners that were competing with each other. Everyone had their own role, and that was really clear"* (Project C). The intra-project knowledge sharing was seen by Project Leader R as beneficial:

> You are forced to cooperate in a context in which you encounter things you will not know, because as regular companies you are usually really doing your own thing. I see that by all means as an import form of knowledge development. (Project Leader R)

At the intra-project level, we identified two sublevels at which knowledge sharing took place (see Figure E.2). We differentiated knowledge sharing within work packages (Sublevel 2.1) from knowledge sharing at the project level (i.e. between work packages or between project partners in general) (Sublevel 2.2).

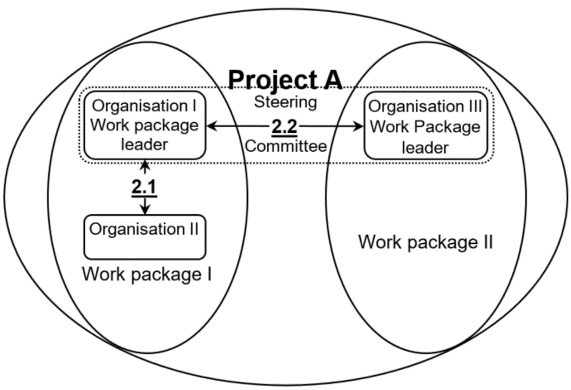

Figure E.2: Sublevels for intra-project knowledge sharing

First, the consortia divided the responsibilities into work packages. Although it was possible that certain work packages were the sole responsibility of a partner, many work packages involved collaborative efforts and thereby created both an interface and a necessity for knowledge sharing to enable the combination of different knowledge bases (Sublevel 2.1). To structure this collaboration, work package leaders organised monthly meetings to discuss their progress on their objectives, although the frequency of these meetings differed depending on the project stage. The project execution often required the exchange of knowledge with a tacit dimension, which might explain why project leaders preferred face-to-face meetings:

> We came to the conclusion fairly quickly that we had to be close to each other because we did a lot of work packages together; let us make sure that we see each other regularly at least and not everything has to be done by phone or email.
>
> (Project Leader K)

Second, the collaboration in projects required also the exchange of insights between work packages to realise the project goals (Sublevel 2.2). Regular meetings for all work package leaders, which were sometimes attended by advisory board members, were organised to discuss the overall progress and inter-work package collaboration of the project. The project leaders also made clear that the project partners were selected to complement each other's knowledge while at the same time avoiding too large of a consortium. This facilitated knowledge sharing within the project. Project Leader K stated:

> I notice that with very large European projects, everyone is going to do his or her own thing, and that there was little cohesion. This project – because it had a nice size, and because not too many people per organisation participated – you could just sit together and just share with each other. (Project Leader K)

Although knowledge sharing at the project level often happened without a clearly defined strategy, there were exceptional cases in which such an in-depth strategy was developed. In one case, the project collaboration resulted in the project leader being recruited by one of the other consortium partners once the project was complete. Project-internal knowledge sharing also took place with citizens that were involved, sometimes even as a formal project partner, because the new technologies (i.e. smart dishwashers) were installed in their homes. Project Leader J stated:

> It is ideal to have a partner like [anonymous university], who takes responsibility for engaging with the residents, organising resident evenings to discuss this topic (. . .) We had a good student who acted as an independent party and formed a bridge between the residents and us, the technicians. (Project Leader J)

Further information to these involved citizens was also provided through brochures, presentations and websites clarifying how to use the technologies and their relevance.

The project leaders were generally satisfied with intra-project knowledge sharing, and the interviews indicated that the partners were often open and willing to share their knowledge with their project partners. Respondent E even said, *"We share everything"*. Nevertheless, they also encountered barriers to knowledge sharing at this level. As mentioned above, one of the conditions for knowledge sharing at this level is the absence of direct competitors. However, in the emerging market of smart grids, future market roles are not yet clearly defined, and the projects can help to explore these roles:

> Every organisation was allowed to explore its future role. An electricity distribution company wants to go in one particular direction, but an energy supplier wants to go in a different direction. (Project Leader C)

Nonetheless, this was also a potential source of conflict: *"They start activities that are the same as ours, and that is sometimes a concern for us"* (Project E). It was also observed that the different interests of organisations sometimes limited the knowledge shared:

> I truly believe that these parties have also gained knowledge in this project which other parties would be interested in, but they simply do not share it because it might give them a commercial advantage. (Project Leader F)

Moreover, in other situations organisations preferred to pursue their own interests, leading them to neglect their interest in the overall project idea:

> A lot of these projects provide (. . .) additional income for companies: (. . .) you take the money, you execute your part, the framing that it is one project is often wrong and everybody goes afterwards their own way. (Project Leader O)

In other cases, the way organisations pursued their own interests was more nuanced, such as when organisations quit their involvement in a project after the initial meetings because the knowledge developed in the project was too abstract and *"too much long-term for some parties to be relevant"* (Project K).

Another barrier was personnel turnover, resulting in a lack of continuity in the knowledge generated in the collaboration. While the consortia indicated that they had benefited from the involvement of PhD and master's students, these students' departure from the project upon graduation resulted in the loss of their developed expertise. In one project this happened prior to graduation, when a talented PhD student was acquired by a multinational abroad. Moreover, the passing away of key employees and the bankruptcy of leading project partners harmed knowledge continuity. Consortium C attempted to ensure continuity by codifying knowledge for internal use:

> During the project a considerable number of people were replaced. After all, it was three years, and every new work package leader needs to familiarise themselves with how things were done before (...). If you codified this part, it can take away a part of this pain. (Project Leader C)

Project Leader E considered it merely an individual responsibility to safeguard the continuity:

> maintaining the thread, I am the one who has been there from when it started with a few colleagues (...) I am the one securing the original idea (...) I absorbed the input of the work packages, I fitted that into the bigger picture. (Project Leader E)

4.3.3 Inter-project knowledge sharing

When discussing knowledge sharing at the inter-project level, several project leaders were visibly annoyed by how it functioned: *"We [the companies involved in Dutch smart grid projects] sometimes invent the same wheel in multiple places"* (Project J). We identified three sublevels at which knowledge sharing took place between projects (see Figure E.3). We distinguished between knowledge sharing with unconnected projects (Sublevel 3.1), knowledge sharing via partners present in both projects due to overlap in consortia (Sublevel 3.2) and building further on the generated knowledge in follow-up projects (Sublevel 3.3).

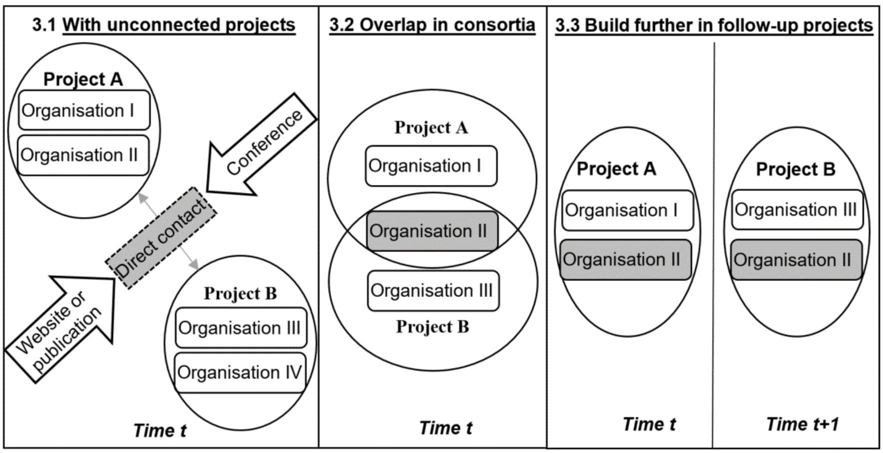

Figure E.3: Sublevels for inter-project knowledge sharing

First, sharing knowledge with unconnected projects, so other projects led by consortia of different partners, was a primary aim of the funding programmes (Sublevel 3.1). These exchanges tended to be initiated via face-to-face interactions during the smart grid conferences organised by RVO.nl. Although the project leaders were generally positive about these events, they observed that the knowledge exchanged remained generic: *"Everything is presented to a broad audience, which makes it very generic"* (Project L). While agreeing with this point, Project Leader H also acknowledged the value of interactions with participants from other projects:

> During the coffee breaks, you hear a lot of interesting information that people do not share formally but are willing to share informally. If you publish a paper on behalf of a project, you should treat the feelings of oversensitive partners with care, because that paper will still be available ten years later." (Project Leader H)

In a similar vein, congresses were seen as useful for establishing contacts, which could lay the foundation for future contact: *"If you see each other at least every once in a while at a congress, and if you then have a query, the telephone can be used."* Project Leader L indicated that while the general events were too generic, project websites could be used to obtain information about ongoing sector developments:

> I look at the results. I am curious about what they have achieved, in case I might ever have a similar project, I will look closely at how they did it. (Project Leader L)

While this could be done by reading a final project report, direct contact seems to be preferred: *"If you know someone, then I am inclined to call him; hey, explain this"*. Some project consortia explored possibilities for collaboration:

> One project in particular was appealing to us – that was [anonymous project]. We found that really interesting, and we visited that company twice, a collaboration or the intention to, and we have considered applying it[the idea of the other project] in one of our projects. (Project Leader B)

However, the interactions between unconnected projects remained superficial, and we did not observe cases of in-depth knowledge sharing or collaboration between unconnected projects.

Second, knowledge sharing between projects with overlapping consortia was more prevalent (Sublevel 3.2). In one of these cases, a research institute applied the same IT solution in multiple projects, benefitting from the knowledge generated in all these projects. Sometimes, this also resulted in joint publications, in which the knowledge developed during several projects was brought together. Considering that participation in multiple projects is a precondition for assuming this bridging role, only the larger research institutes, multinationals and electricity distribution companies were able to do this. The latter also played an active role by organising joint knowledge sharing sessions for the consortium partners of their projects. The project leaders indicated that they benefited from these sessions, which allowed them to go more in-depth than at the large-scale conferences:

> That was really useful. That allowed in-depth knowledge sharing; sharing of generic information is already happening enough. I am a technician, and want information on a detailed level, and not too generic. (Project Leader L)

Third, eight consortia discussed or initiated follow-up projects to further build upon the knowledge developed during the current project (Sublevel 3.3). In most of these cases, the same consortium reapplied the knowledge in a new project, although there were also cases in which consortium partners formed new consortia for this purpose.

There were quite some differences in the frequency of knowledge sharing and the barriers at play within the different sub-levels of inter-project knowledge sharing and the barriers at play for the different sub-levels. While for projects with overlapping consortia or follow-up projects, knowledge sharing happened naturally, none of the projects realised in-depth knowledge exchange with unconnected projects. The reason for this could be that the latter requires more deliberate planning, which is difficult for consortia to do while under pressure to complete their own objectives. This could also be why most project leaders, although they indicated that they were open to sharing knowledge with other projects, expected the other side to take the initiative:

> On the one hand, it would help them if they would know what we are working on, but I am not going to take the initiative. [Anonymous] is located close to the German border. There is not really a need for me to go there, but we can give them some advice on their issues. (Project Leader A)

However, proactively offering help was sometimes not appreciated, as in the case of Project K:

> With some issues there were possibilities of which we thought we could assist, but I saw that quite some projects had a pretty closed vision of doing their own thing: "yes, this could be interesting, but we are not going to do this together." (Project Leader K)

Several project leaders also expressed a lack of interest in the other projects:

> The other projects were not that interesting, that was about smart grid and sharing with horticulturists. . . mwah. . . .that is not so interesting, our project is special in focus. (Project Leader B)

When project leaders knew about other projects with whom there were no formal ties, informal networks seemed to play a role: *"I know one of these projects quite well because a friend of mine is involved in it"* (Project N). In addition to the lack of interest, some project leaders expressed that inter-project knowledge sharing was not relevant because they saw themselves as frontrunners:

> We were far ahead in comparison to the other projects. For us knowledge sharing was helping them, and we have been reluctant in that. On the one hand, you do not want everyone coming up with the same solution, because you do not know whether it is the right one. On the other hand, you do not want to spend your time helping others, while we also had ambitious plans to realise. (Project Leader C)

4.3.4 Project-external knowledge sharing

The knowledge sharing at the project-external level was quite diverse in its mechanisms, audience and content. There was no real consensus in the interviews or in the final project reports about what was understood as external knowledge sharing, although there was importance given to codified knowledge and a process characterised by dissemination with unidirectional knowledge-sending. We identified two sublevels at which knowledge sharing took place (see Figure E.4). We distinguished between knowledge sharing carried out by the project leader from the project level (Sublevel 4.1), and knowledge sharing carried out by the individual organisations within the project (Sublevel 4.2).

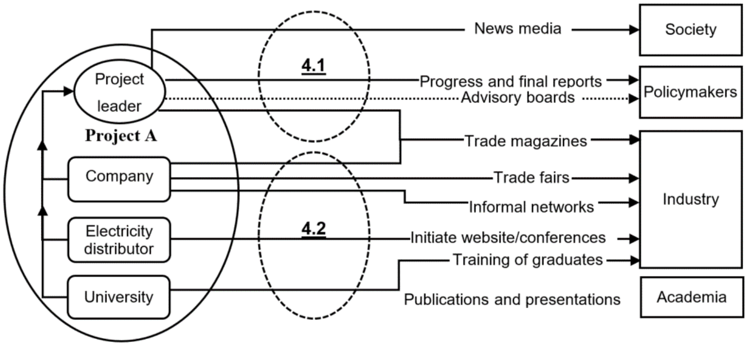

Figure E.4: Sublevels for project-external knowledge sharing

First, when discussing project-external knowledge sharing, most project leaders referred to the knowledge that was shared from the project level (Sublevel 4.1). They saw it as their main responsibility that the compulsory deliverables such as the final report and progress reports were written. These reports were available for nearly all the projects after their completion. While the progress reports were limited in scope, most final reports provided in-depth insight into the project's findings. Many project leaders saw these documents merely as boxes to tick and as an obligation coupled to receiving the funding, complaining that the time invested in these reports could hinder project completion.

In contrast, most project leaders were proud of and willing to invest time in publications for trade magazines. In addition, a couple project leaders were invited to join advisory boards, using these opportunities to stay up to date on and to influence policy in their desired direction, such as by asking for attention to be paid to the value of flexibility for the grid. In a similar vein, Project K aimed to influence other actors: *"Communication is as important as the technical content of the project because you want to push people to do something and not only present something technical."* Furthermore, (local) newspaper articles and videos were targeted to create awareness among the general public of the developments happening in their environment without addressing all the project details. Project Leader L said:

> It is a constant process; I am not at my desk for six months, and only then do I start communicating (...) When I have found something, and I am with the client, and it is discussed, it is immediately shared (...) It is not that you are going to wait for a report to be approved; that is a continuous process.
>
> (Project Leader L)

Second, knowledge sharing activities were also deployed by the other consortium partners (Sublevel 4.2). Some consortia saw publications as a shared responsibility: *"These publications are always [written by] a combination of partners"* (Project C). This contrasts other projects, in which the partners have their own publications, which is indicated in the final report with each partner's list of publications. The focus areas of the types of partners also resulted in different forms of knowledge sharing. The universities and research institutes, pressured by the publish-or-perish culture in academia, often engaged in knowledge sharing by writing and presenting scientific and conference publications in English, targeting a global academic audience. The universities also shared the knowledge developed in the projects with their students (e.g. in courses and especially by means of graduation projects), and they are thereby said to be contributing to the training of 'the experts of tomorrow'.

Private companies, in contrast, were mainly interested in displaying their skills and products to potential customers. By appearing in trade magazines and presenting their products at trade fairs, these companies were considered to have disseminated market knowledge: *"I would like to present our story in Africa and China (...) I want to market this project"* (Project P). Project Leader P also actively shared in-depth knowledge with an American company in their network to support the US implementation of a product developed in the project for which there was not yet a viable business case in the Netherlands. Actively sharing knowledge not only with companies but also within the sector helped several project leaders establish a good reputation and a strong position within the sector. Acquiring a position within the sector also motivated some firms to share knowledge, as they were convinced that this would allow them to position themselves well in the new configuration of actors in the sector; new business models were a concern for later.

The electricity distribution companies were in a different position, as regulations and bureaucracy limited their possibilities to experiment with new technologies. Nevertheless, as the main beneficiaries of the adoption of smart grids, they played a facilitating role for knowledge sharing within the sector. The electricity distribution companies, often in collaboration through the industry body Netbeheer Nederland, organised conferences to which industrial, societal and policy actors were invited. They additionally started the initiative energiekaart.nl, a knowledge portal which aims to provide a comprehensive overview of all smart grid initiatives, technologies and experts in the Netherlands.

Considering the barriers, knowledge sharing at the project-external level was not something that simply occurred; it required deliberate coordination and planning. As Project Leader K noted about not meeting the idea to send frequent newsletters: *"(...) we send four or five, because it are things you need to think about, and on that the planning was not strict enough."* Some projects (e.g. Projects F, H and O) had work packages designated for knowledge sharing. Although the project leaders were usually expected to take the lead on knowledge sharing initiatives at the project-external level, they depended on input from the other consortium partners. In some cases the partners were unwilling or unable to invest resources in writing sections for project reports, while in other instances the partners were willing to share knowledge, but the project leaders noticed that they were only sharing part of the knowledge. Most project leaders understood that the partners were not going to share all the knowledge developed prior to the project, but they also stressed the importance of project-external knowledge sharing and that this was necessary to justify the subsidies they received.

Some project leaders pointed to lack the financial and human resources for project-external knowledge sharing, which they explained by not including it in the project planning and budgeting. Many of them, also referring to experiences from other projects, explained that knowledge sharing was not a top priority. This was especially the case for projects that were behind schedule and needed to focus on delivering the project on time. Sometimes these consortia were also reluctant to share because they preferred not to disclose the failure of some of their technologies or a lack of results in general.

Furthermore, the focus of universities on publishing led to a neglect of other knowledge sharing activities; this appeared to be the case with PhD students whose top priority was finishing their PhD study on time. While many of these publications were openly accessible, some were hidden behind paywalls, which supports the impression of Project Leader J, who suggested that these publications were primarily for the academic community:

> It is for a different audience (...) Scientific research are heavy papers, English, technical, scientifically sound. It is not easy for a project organisation to understand. (Project Leader J)

Furthermore, peer-reviewed publications seemed also to suffer from a success bias, which was apparent in that unsuccessful projects were less involved in publishing.

The effect of these barriers is visible in the survey results. Most organisations (93%) acknowledge the necessity to acquire knowledge about smart grids for the future of their organisations; of these organisations, only a few were planning to develop this knowledge internally. Hence, the large majority of the respondents were outward-oriented in their search for knowledge, resulting in a large potential for knowledge sharing with external organisations. However, 30% of organisations were still unaware of the existence of the subsidised projects. That said, of the respondents that knew the projects by name, 80% were aware of what was done in that project. They primarily acquired knowledge via trade magazines and existing relationships within the sector. Only one respondent indicated having acquired knowledge through scientific publications. Although the projects are actively engaged in knowledge sharing with external organisations, the visibility of the projects by external organisations remains limited.

The project-external knowledge sharing was mainly unidirectional in the sense that the knowledge developed in the project was provided to external actors, and often not considering whether this knowledge would actually be used by the actors. In the few cases in which a consortium partner aimed to obtain knowledge from an external actor, other consortium partners enabled this interaction by introducing them to a relevant partner in their network. On another occasion of acquiring external knowledge, a multinational encountered resistance from an SME which feared that the multinational would take advantage of opening up the knowledge base. To overcome this obstacle, a smaller project partner stepped in with whom the SME felt more comfortable sharing knowledge. That this fear was not unjustified showed the case of Project N, in which a larger organisation threatened to copy products.

4.4 Discussion

Intra-organisational, intra-project, inter-project and project-external knowledge sharing are four distinct levels at which knowledge is shared; each level contains sub-levels at which knowledge is shared via multiple mechanisms and influenced by various barriers. Table E.1 on page 216 provides an overview of the main findings.In general, there seems to be a trend that at the intra-organisational and the intra-project levels, knowledge sharing is about interactions involving specific and tacit knowledge, whereas at the inter-project and the project-external levels, it is more about the dissemination of generic and codified knowledge. Possible explanations for this include larger geographical and institutional distances and the absence of incentives at the latter two levels.

Expecting the consortia to excel at every level is unrealistic. The project leaders that are heavily involved in intra-organisational knowledge sharing are likely to have less time to focus on what is happening within other projects. However, it is not only this scarcity that creates competition between the levels; the prevalence of successful knowledge sharing at one level can also reduce the need to be involved in knowledge sharing at other levels. Furthermore, there is inevitably some interaction between the levels; knowledge sharing with overlapping consortia, which is presented as knowledge sharing at the inter-project level, often also requires intra-organisational knowledge sharing. Similar arguments can be made for knowledge sharing at the intra-project level, such as consortium participants who contact each other to address an issue and who subsequently source the required expertise within their own organisation. Interactions between intra- and inter-organizational knowledge sharing have also been discussed in the literature (e.g. Easterby-Smith et al. (2008)). In this, organisations seem to follow a transaction cost logic (Williamson, 1979) in which they aim to limit costs by sourcing knowledge at the lowest level possible, starting at the intra-organisational and, when necessary, contacting consortium partners, but seldom consulting other projects or external actors for knowledge. And this is an important finding as these levels of knowledge sharing are key objectives of the funding programmes. The fact that this not happens by default indicates the need to identify the specific the barriers.

At most levels we see personal level networks recurring as facilitators of knowledge flows. Individual employees use their connections to share knowledge at the intra-organisational level. Moreover, at the intra-project level, the employees of the consortium partners share their knowledge. Inter-project knowledge flows happen when employees form a bridge between projects. Only in the case of project-external knowledge sharing are personal networks less dominant, and this seems much more about finding the right distribution channels.

Table E.1: Summary results

Level	Sub-level	Mechanism	Knowledge	Prevalence	Main barriers
1. Intra-organisational	*1.1 With colleagues in the same office*	Requests for help from local colleagues	Specific expertise present in colleagues	All organisations	A lack of awareness of available knowledge and of relevant colleagues
	1.2 With colleagues in offices in the same country	Information requests; influencing direction of research; Jointly participating in projects	Specific information;	Only in larger organisations	
	1.3 With colleagues in offices abroad	Participation in matrix structures	Strategic knowledge; Expertise specific to the project	Mainly in multinationals	
2. Intra-project	*2.1 Work packages*	Work package meetings and collaboration	Practical knowledge for execution work packages	Most work packages	Different interest of project partners; Lack of continuity due to personnel turnover
	2.2 Project level	Project meetings; joint development	Knowledge on progress of work packages to assure alignment and project	All projects	
3. Inter-project	*3.1 Unconnected projects*	Face-to-face interactions, possibly initiated during events organised by RVO.nl; websites	Coordination	Not more than superficial interaction	Wait and see attitude; Lack of interest in other projects; Knowledge sharing with other projects was considered not necessary
	3.2 Overlapping consortia	Shared partner transfers knowledge; joint publications; workshops	In-depth Knowledge sharing for instance on IT-solutions	Six projects	No barriers observed
	3.3 Follow-up projects	Knowledge embodied in individuals and organisation is transferred	Experiences and technologies	Eight projects	No barriers observed
4. Project-external	*4.1 From project level*	Deliverables via project leader, project marketing	Generic progress updates	All projects	Lack of resources, interest and incentives for external knowledge sharing
	4.2 By individual partners	(Scientific) publications; marketing developed products; training	Scientific knowledge; market knowledge	Most projects	

Considering that the lack of knowledge is a bottleneck to the further development of smart grids (Muench et al., 2014; Nemet et al., 2018), with this study, we contribute insight into the different levels and sublevels of knowledge sharing along with the different mechanisms that can play a role in overcoming this bottleneck. This systematic overview was missing in the literature. Given that knowledge sharing among projects was a primary aim of the funding programmes and the fact this study shows that this knowledge sharing hardly happens between unconnected projects, show the importance of our approach and calls for policy interventions. A variety of such policy, as well as managerial, interventions will be discussed in the next section. This research thereby makes a relevant contribution to ongoing academic and policy discussions. Part of our message complements that of Naber et al. (2017) who stressed the importance of understanding the inter-project learning processes for up-scaling; we add to this perspective a more holistic approach by unfolding the levels at which the knowledge generated in pilot projects is shared and for each level the mechanisms, the knowledge as well as the barriers.

5 Conclusion and policy Implications

5.1 Summary

Interviews with the project leaders of sixteen smart grid pilot projects, complemented with desk research and a survey, provided insight into how knowledge is shared in pilot projects at the intra-organisational, intra-project, inter-project and project-external levels. Not only across these levels but also across the sublevels present within these levels, the shared knowledge differs, as do the mechanisms and barriers. We opened the black box of knowledge sharing in pilot projects. The results indicate that the majority of knowledge sharing takes place at the intra-organisational and intra-project level. Knowledge sharing across projects is mainly happening when projects have overlap in consortia and when follow-up projects are initiated. Knowledge sharing at the external level is mainly unidirectional (sending) and encompasses generic knowledge about the project. This study is the first that opens the black box of knowledge sharing in pilot projects. This unravelling of the knowledge sharing dynamics at these four different levels appears to be necessary as in general the knowledge sharing is less than what policymakers aim for and less than what is required for the transition to a sustainable economy. The results of the study reveal what the challenges are and therefore lead to a set of policy and managerial recommendations, but before discussing these we need to note two limitations and recommendations for further research.

5.2 Limitations and recommendations for further research

The perspective of the project leader could bias the findings of this study. Yet, we expect this effect to be limited since there were no noticeable differences in the answers of the interviewees in duo interviews and because project leaders employed by a large variety of organisations were interviewed. Nevertheless, further research could address this concern. While this study offers in-depth insight for the smart grid sector in The Netherlands, caution must be applied to prevent an overgeneralisation of the results. The complexity of the smart grids technology makes collaboration crucial (Planko et al., 2019). In sectors with less complex technologies it might for instance be easier to find the relevant person in the organization (barrier intra-organizational knowledge sharing) and the sharing of context specific knowledge might be easier (inter-project knowledge sharing). Also the role of important actors such as electricity distribution companies in the energy sector, can be different in other countries and are not part of the actor configuration in other sectors. Probably other actors will take up a similar central role. In order to apply the framework it is important to know the specific actor configurations. We think most of our findings (e.g. the different (sub)levels, mechanisms and barriers) will still be observed in other sectors, but we highly recommend research designed to allow for quantitative analysis. A concrete suggestion is to conduct a survey of the consortium partners of a large number of projects (not necessarily smart grid projects) to gain insight into the knowledge sharing dynamics across industries and countries.

5.3 Policy and managerial recommendations

With the present study we aim to involve policymakers and the management of the consortium partners in a debate about both the desirability of knowledge sharing at the different (sub) levels and ways to facilitate this. There is likely to be a contrast in the perceived desirability of sharing knowledge at these levels between policymakers and the (private) consortium partners. As we have seen in our cases there is a stronger interest among consortium partners to share knowledge at the intra-organisational and intra-project level compared to inter-project knowledge sharing and project-external knowledge sharing, which was looked for by policymakers. This difference makes that we propose different solutions for different actors (policymakers and consortium partners) at the four levels to stimulate knowledge sharing. The coming sections briefly discuss for each level the main policy and managerial recommendations.

5.3.1 Intra-organisational knowledge sharing recommendations

The main barrier consortium partners are facing relates to the lack of awareness considering the knowledge available at relevant colleagues within the organisation. To overcome this managers from the consortium partners can use tools, such as intra-organisational seminars, to disseminate the knowledge of projects within the organisation. In addition an up-to-date overview all the projects in the organisation (with offices in the same country) and an overview of themes and knowledge within the different offices also abroad will enable employees to find possible synergies and ways they can contribute with their expertise. Policy makers can facilitate this by asking applicants to summarize the smart grid knowledge and expertise available within the organizations as well as to develop a dissemination strategy for the developed knowledge in the different (international) organisations.

Organisations should also provide some flexibility with regard to the human resources to be involved in the projects; several project leaders noted that only during the project it became clear what exact expertise was required for the successful completion of the project, and indicated to have benefited from the possibility to access this additional expertise that was already available within their organisation. In certain cases these changes in the required human capital could alter the distribution of funding among the consortium partners. While this was something to be agreed on within the consortium, a few project leaders also expressed their concern that such changes could lead to a re-evaluation by the funding agency of the project and the funding, and hence were reluctant to utilize these opportunities. To resolve this, funding bodies and policy makers should be open to this and should allow for more flexibility and clarify the conditions considering potential re-evaluations.

5.3.2 Intra-project knowledge sharing recommendations

Collaborating in these pilot projects creates interdependencies; partners are likely to depend on the work of other partners for the completion of their own tasks. It is crucial that partners feel committed to the project and feel free to be open about the eventual challenges they face. In general we observed that the larger the project, the less coherence and transparency project leaders encountered. Moreover, different organizations have different interests, which can hamper knowledge sharing. Especially the presence of competitors, or consortium partners that that could develop into a future competitor, could harm knowledge exchange within projects. For the project leaders it is therefore important that all partners commit to the project and that they create an environment in which all partners are and feel free to share their ideas. Commitment can potentially be arranged formally by having contracts and investing own resources. Additionally, project leaders should invest in trust-building among partners to create a beneficial environment for knowledge sharing.

Funding bodies could play a facilitating role by carefully considering the size of projects and potential competing interests within the consortium. And by providing additional funds for organizing events to get to know and select the partners.

Similarly to the concern regarding the attraction of additional expertise from the intra-organisational level, consortia should have the freedom to add new partners in case they are faced with challenges that are outside their area of expertise or when partners or specific persons leave the project. Project leaders should acquire new expertise, and make sure relevant knowledge is codified in guidelines or tutorials, to facilitate the replacement of partners or persons. Policy actors could play a facilitating role in this process by utilizing their network to find new partners that could deliver the missing expertise as well as by encouraging the codification of knowledge.

5.3.3 Inter-project knowledge sharing recommendations

We identified several barriers for knowledge sharing with unconnected projects. These are the wait and see attitude of project leaders, the lack of interest in other projects, and the observation that knowledge sharing with other projects was considered not necessary. This indicates that behavioural change is required to enable this kind of knowledge sharing, in which policy makers can play an important role. Policymakers should employ recurring initiatives in which consortia with relatively little effort can share their lessons with other projects, for example by means of workshops. Targeting the public funding at the development of open source solutions for common challenges might also be part of a strategy, although caution should be applied to prevent lock-in to one technology. The consortium partners should consider what benefits can be obtained from participation in these initiatives and incentivize their employees accordingly.

Sharing knowledge with other projects via shared partners is already taking place more naturally. In this way expertise and IP, for example in the form of IT knowledge, are being shared between projects. For consortium partners, this requires intra-organisational coordination of smart grid projects to identify potential synergies. Also policymakers should evaluate if there are certain synergies possible, while keeping in mind that potential technological lock-in should be avoided.

While follow-up projects could be useful to take the next step with a technology, actors and policymakers should keep re-evaluating whether the technology still has potential and need for public support. Requiring projects to formulate and reflect on potential next steps in the final report could be a useful in this regard. Based on this policymakers can make their evaluation, and could guide them through the jungle of all the different national or transnational funding opportunities.

5.3.4 Project-external knowledge sharing recommendations

We identified several barriers for project-external knowledge sharing. These are lack of financial and human resources; lack of interest in external knowledge sharing; incentive structure of own organization to focus on just one specific type of knowledge being shared.

In order to overcome the lack of financial and human resources, consortia should be encouraged to upfront budget in this knowledge sharing. If this knowledge is important for the success of the funding program policy makers should make this a stand procedure in the application. And project leaders should be aware of this and think about strategies to include this knowledge sharing from the beginning onwards.

Moreover in order to overcome the lack of interest in external knowledge sharing, consortia should be encouraged and facilitated to share all their best and worst practices with the wider community. Since this will primarily generate social returns, policymakers should take the lead in this process and make this as effortless as possible for the actors. This could be done by offering straightforward templates for reporting the successes and failures of a project and offer platforms on which these can be disseminated. However, consortia need to carefully discuss what experiences can be shared without harming the interest of one of their partners.

Even though the scientific knowledge production system is currently changing in The Netherlands with increasing attention to open access and valorisation of knowledge, the fact that the careers of researchers is still heavily depending on peer-reviewed scientific publications was experienced as a barrier to the use of other mechanisms for sharing knowledge. Being aware of this is the first step. But there are also other options to share the developed knowledge while still obtaining private returns for universities, researchers and market actors. Knowledge generated in projects is currently already used to inform teaching activities, which could be developed further into specialised educational programs. A first step could be to develop minors. Moreover, other project partners could contribute by giving guest lectures, subsidizing tuition fees and guaranteeing employment for graduates. In general market actors can strengthen their smart grid knowledge by a focused hiring strategy. This can also be realized by offering industrial PhDs-projects. To realize this policy pressure as well as support could be useful.

5.4 Concluding remarks

To conclude, knowledge sharing is crucial for the transition to a smart energy system. It is however not an automatic process at the four different levels of knowledge sharing. Our approach enables a clear identification of the type of knowledge shared, the mechanisms as well as the barriers for each of the sublevels, resulting policy and managerial recommendations. While the intra-organisational and intra-project level generate private returns, coordination related barriers need to be overcome by both individual consortium partners as jointly in the consortia. The social returns of inter-project and project-external knowledge sharing that cannot be appropriated by the private actors involved in the projects create a demand for policy intervention to realize knowledge sharing at these levels. We call for the use of this framework from the early stages of the funding process to structure discussions on how funding tender design and evaluations could be fitted to reach the desired knowledge sharing. Part of such a strategy could be requiring applicants to specify their knowledge sharing strategies for each sublevel. Realizing these knowledge spillovers is key to the effectiveness of these projects for realizing the desired change in the energy sector.

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Paper F

Doctoral Graduates' Transition to Industry: Networks as a Mechanism?

Cases from Norway, Sweden and the UK

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Abstract

Increased public investment in PhD education to drive innovation has led to a recent rapid growth in the number of PhD graduates. As academic labour markets have not developed at the same pace, an ever-larger share of the graduates is finding employment in industry. However, the transition from academia to industry is not always easy, and mismatches occur between the graduates' profiles and expectations and industry needs. To prevent such mismatches, we need a better understanding of the process of this transition. The present study aims to provide insights into the role played by PhDs' networks in the job search after graduation. Our data comprise 31 interviews with industry-employed doctoral graduates in the science, technology, engineering and mathematics (STEM) disciplines from Sweden, Norway and the UK. Professors are generally expected to support their PhDs in finding a job after graduation, particularly as they play a central role in university–industry links. Our findings show that PhDs' autonomously built personal networks can help match their specific scientific expertise with labour market demands. We distinguish country-specific patterns and characteristics of the transition, in which regional career paths are more (Scandinavia) or less (the UK) noticeable. Finally, the study has practical implications, in particular for doctoral students and PhD graduates, related to their career orientation post-PhD.

Preface

Similar to most projects, the RUNIN project is divided into a set of work packages. Along with Eloïse Germain-Alamartine, Rhoda Ahoba-Sam, and Saeed Moghadam-Saman, I was part of the 'people and networks' work package. Since our first encounters, we entertained the idea of writing a paper together. During a training week in Copenhagen in November 2018, we began exploring the possibility of a joint publication, finding common ground in the topic of the role of networks in the transition of PhD graduates to industry. Subsequently, we presented the paper at an International Research Seminar on Post-Phd Careers in March 2019 in Amsterdam and at the GEO-INNO conference in Stavanger in January 2020. The paper was accepted in March 2020 for publication by Studies in Higher Education.

1 Introduction

In the last few decades, the number of PhD students annually trained by universities in OECD countries has increased markedly (OECD, 2016). This increase is, however, in strong contrast with the little growth in the number of available academic positions for which these graduates are traditionally trained (OECD, 2016; Larson et al., 2014). Consequently, more and more doctoral graduates are searching for jobs outside academia (Bloch et al., 2015). Although unemployment among this group is lower than in the general population (Auriol, 2010), an increasing share end up in positions for which they are overqualified or which are outside their specific field of expertise (National Science Foundation, 2012).

The latter developments are often explained by the very specific scientific expertise developed during PhD training, which makes it difficult for graduates to find a job matching their education and skills outside academia (Maki & Borkowski, 2006). In response, many scholars and policymakers have argued that more attention should be given to the development of generic skills in doctoral schools (Thune et al., 2012; Vitae, 2011; LERU, 2016). This could potentially begin to close the gap between the skills of PhDs and industry demand – although solely relying on this can limit the added value of doctoral education over Master's education (Brennan, 1998; Hager et al., 2002; De La Harpe et al., 2000). Hence, different mechanisms may be used for finding suitable jobs outside academia to complement these kinds of initiatives.

Adding to research on the gap between skills and PhDs' employability, we argue that an in-depth understanding of the current processes by which PhD graduates obtain employment in industry is necessary. Existing knowledge is mostly focused on the destination of doctoral graduates (Auriol, 2007; Drejer, Holm, & Østergaard, 2016), with little insight into the actual transition process (Manathunga et al., 2009; Cruz-Castro & Sanz-Menéndez, 2005). Granovetter (1974) stressed the importance of networks as enablers of labour market matching processes by reducing the search costs and uncertainty involved. We therefore posit that network connections with industry actors may fulfil a similar important role in PhDs' job searches, especially since more and more PhD studies transcend academic and industrial settings (Wallgren & Dahlgren, 2007; Thune, 2009), offering opportunities to develop these ties (Lam, 2007). Additionally, there is some research suggesting that PhDs in some cases could benefit from their supervisors' networks (Bøgelund, 2015).

While university–industry connections undoubtedly play a role in the labour market matching process, there is little research on the importance of these networks for doctoral graduates entering industry. The increasing trend of doctoral graduates moving to industry, either by preference or owing to external factors such as labour market conditions, asks for a deeper understanding of the university-to-industry transition process. Hence, this study aims to explore the transition of PhD graduates to industry, looking more specifically at how university–industry networks, as well as the regional and national contexts, explain such transition.

In the qualitative research approach adopted, 31 interviews were conducted and analysed. In order to ensure both diversity and comparability, the interviewees were STEM doctorates working in industry who had graduated from universities in Sweden, Norway or the UK situated either in the central or a peripheral region. The findings show that networks play an important role in increasing the quality of non-academic employment after graduation, by matching PhDs' specific scientific expertise with labour market demand – but these networks are built by the PhDs themselves, with little support from their supervisors. Additionally, there are country-specific patterns and characteristics of university–industry transitions. These findings thus contribute to the literature on university–industry networks as well as the literature on the employment of highly educated workers.

2 Literature review

2.1 Challenges with employment opportunities for doctoral graduates

With the democratization of higher education in the past century, there has been an increasing supply of highly educated workers on the labour market (Auriol et al., 2013; OECD, 2016). This phenomenon goes along with the shift towards a knowledge-based economy in the European Union and consequently increasing demand for such knowledgeable individuals (European Council, 2000). While the annual growth in absolute numbers of graduates is largest at undergraduate level, the relative growth is largest among PhDs (OECD, 2016).

Doctoral graduates are traditionally educated to conduct research in the area in which they have become experts and to teach in higher education institutions (The Group of Eight, 2013). However, although an increasing number of university students has created a greater demand for doctoral graduates in the academic labour market, the growth in the availability of such graduates seems to have exceeded the demand. This imbalance in demand and supply has led to a bottleneck in the academic career progression of PhD holders (Andalib et al., 2018; Etmanski et al., 2017; Larson et al., 2014; Neumann & Tan, 2011).

Increasingly, therefore, doctoral graduates are leaving academia to work in industry (Bloch et al., 2015; Herrera & Nieto, 2013). Being highly educated (EHEA, 2018), it might be assumed that they have privileged access to the industrial labour market in knowledge-based economies. However, there are many mismatches on this market (Cedefop, 2016; Gaeta et al., 2017; Allen & Van der Velden, 2001): skills mismatches, field-of-study mismatches and over-education or qualification mismatches (Corcoran & Faggian, 2017), of which the latter has received the most attention in the literature (Green & McIntosh, 2007; McGuinness & Byrne, 2015; Mcgowan & Andrews, 2015). Employment mismatches need to be addressed because they entail a sub-optimal use of human capital, leading to a decrease in productivity (Mcgowan & Andrews, 2015; McGowan & Andrews, 2017). This further suggests that the problems doctoral graduates face on the industrial labour market is not purely quantitative as is the case with the oversupply of PhDs on the academic labour market, but more about realizing a suitable match between their qualifications and the jobs on offer. These challenges therefore call for a closer look at what actually occurs at the university–industry interface.

2.2 University–industry networks and labour markets

The career trajectories of doctoral graduates have been the subject of many studies (Mangematin, 2000; Cañibano et al., 2019), including in their scope both internal factors, such as personal preferences, characteristics of the study and network opportunities (Mangematin, 2000; Jackson & Michelson, 2015) and external factors, such as labour market demand (Bloch et al., 2015). However, the actual means used by doctorate holders to find a job outside academia have received little attention.

Granovetter (1974) pointed to networks as the most important means for facilitating labour market matching. Networks facilitate awareness of the available employment opportunities, as well as providing actors with more information on these opportunities, at relatively little cost. Knowing more enables individuals to better evaluate whether a job opportunity will match their profile. Similarly, employees will primarily refer jobs to individuals in their network who they think will make a good fit with the job and the company. Employers thus reduce the risks inherent in the recruitment process by relying on networks (Holzer, 1987). Reviews of empirical studies show that the majority of jobs tend to be found through networks and that the importance of networks varies only slightly according to the gender, race and sector of those involved (Ioannides & Loury, 2004; Montgomery, 1991). Jobs received through networks tend to be better fitted to the education of the applicant and offer better career prospects (Franzen & Hangartner, 2006).

In doctoral programmes, developing networks has increasingly been promoted as a transferable skill that can be deployed in a wider context than the specific area the students have been studying and that can thereby increase their employability (Sinche et al., 2017; Kyvik & Olsen, 2012). In addition, industry partners are increasingly involved in doctoral education, mostly by funding and hosting industrial PhD programmes (Roberts, 2018; Benito & Romera, 2013; Wallgren & Dahlgren, 2005). This involvement of industry contributes towards fostering networks at the university–industry interface and arguably plays a role in facilitating the matching of PhDs' skills with the demands of industry, thereby smoothing the transition from academia.

The transition could be viewed as a move from the academic internal labour market to an industrial internal labour market. Internal labour markets (ILMs) are the institutional rules and procedures that govern the employment relationships within an organization, such as recruitment, training and the price of labour (Doeringer & Piore, 1985). ILMs are hence distinguished from the external labour market (ELM), which is directly affected by macroeconomic variables. However, ILMs and ELMs can be combined to form an extended internal labour market, when, for example, recruitment channels deploy employees' networks to recruit additional workers (Manwaring, 1984).

This tendency to rely on internal networks is in line with March's (1991) argument that organizations, when looking for new resources or markets, prefer to exploit internal resources to which they already have access, rather than exploring new ones. Lam (2007), studying employment at the university–industry interface, took this concept a step further, arguing that ILMs' boundaries between two sets of organizations become blurred when career and knowledge flows across them are supported by the creation of an overlapping space (Lam, 2007), i.e. the concept of overlapping internal labour markets (OILMs, see Figure F.1).

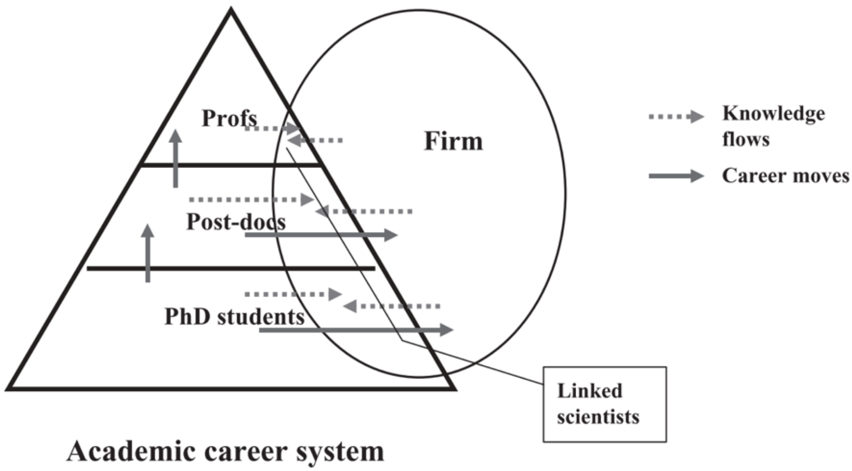

Figure F.1: Career and knowledge flows across the academia–industry boundary. Source: Lam (2007).

The OILM concept explains the forms of career models emerging from industry–university research and development (R&D) collaborations, such as hybrid careers (Cañibano et al., 2019). 'Linked scientists' are researchers whose work roles and careers straddle firms and universities: entrepreneurial professors, postdoctoral researchers who play a major role in collaborative projects and doctoral students who are jointly trained by universities and firms by means of varying arrangements. OILMs, drawing on a pool of linked scientists, can help firms in their selection and screening of candidates for possible recruitment (Lam, 2007). "The idea behind this [OILM] concept builds on that of a firm's internal labour market, and how it may be extended beyond the boundary of the firm following established recruitment channels and social networks" (Lam, 2007, p. 1011).

3 Methodology and data

In order to investigate the role of university–industry networks in the transition of PhD graduates to industry, we employed a multiple case study design. A qualitative approach, based on semi-structured interviews with such graduates, was adopted. This approach enabled a contextual understanding of the university–industry transition and further offered in-depth insights into the social process of networking and its complexities (Eisenhardt & Graebner, 2007; Yin, 1984). The prospects of obtaining rich data from varied sources and the closeness of researchers to the data were further advantages of the approach chosen.

Interviews were conducted with 31 STEM PhD graduates from six universities in three countries: the University of Lincoln and Loughborough University in the UK, the University of Stavanger and the University of Oslo in Norway, and Linköping University and KTH Royal Institute of Technology in Sweden (see Table F.1). The focus on STEM graduates is based on the above-average exposure to industry that these students experience during their studies (Perkmann et al., 2013). Convenience sampling was applied for selecting the countries and universities. Additionally, for each country, universities from both peripheral and central regions were included. Our sample also included both natives and migrants in the selected countries. We are therefore confident that the sample represents comprehensive coverage of the employability dynamics of PhD graduates.

Table F.1: Overview Samples.

	Norway		*Sweden*		*UK*	
	University of Stavanger	**University of Oslo**	**KTH Stockholm**	**Linköping University**	**University of Lincoln**	**Loughborough University**
Year of establishment	2005	1811	1827	1975	1992	1966
Type of region	Peripheral	Central	Central	Peripheral	Peripheral	Central
Number of interviewees	8	2	6	7	5	3

All countries in our sample have experienced a rapid growth in the number of PhDs over the past decade (OECD, 2016). This growth could be attributed in part to the Bologna Process, a series of agreements between European countries to ensure comparability in the standards and quality of higher education qualifications (European Commission, n.d.). The adoption of English as the main academic language has enabled the internationalization of doctoral education in the Nordic countries, nearly all of which is written in English (Hultgren et al., 2014). While the prescribed duration of doctoral education in Sweden is four years – a year longer than in the UK and Norway – delays and extensions are common, which means that PhD education is of a similar duration in these countries as well (EHEA, n.d.).

In Sweden and Norway, the majority of PhD students are employed by the university and receive salaries based on collective bargaining agreements. However, UK salaries for doctoral students often rely on external funding, making for more variability among students and institutions, and the relative wages are generally lower than in the Nordic countries. The differences are also visible in terms of status, supervisor–student relationships tending to be more hierarchical in the UK than in the Nordic countries.

details of the PhD graduates were retrieved through supervisors, university websites and LinkedIn profiles, and the graduates were invited by email to participate in a 30-minute Skype or face-to-face interview in English. The semi-structured interviews were conducted with the help of an interview guide (see Appendix A), which included a set of general topics and several specific questions to ensure comprehensive coverage of each topic. The recordings of these interviews were subsequently transcribed. The analysis consisted of two steps: first, the interviews were summarized in a table to provide systematic oversight of the findings in several areas of interest. Individual transcripts were then analysed, after which the individual insights were synthesized to obtain an overall understanding of the data collected.

The data collected illustrates that myriad factors influencing the transition from academia into industry for PhDs. Most commonly, the industry destination was observed to contrast with doctorands' a priori career goal of remaining in academia. Only 14 out of the 31 informants wanted to be in industry from the start – six of them being from the Norwegian sample – and two had had no firm plan. Notably, only one person (out of 10 informants) from the Norwegian sample wanted to remain in academia from the beginning of the PhD. Generally, this redirection of career trajectory was attributed to factors such as a lack of career prospects in academia, instability/insecurities involved in working on a contract basis and family situation.

The majority of our interviewees moved to industry directly after graduation, many of them acquiring the position before their graduation. Other PhDs stayed in junior positions in academia before making the move to industry. Some of our interviewees even turned down an academic job offer to pursue one in industry – these interviewees had lost interest in an academic career after their first-hand experience during their PhD.

All informants ascribed some relevance of their PhD education, specifically the various disciplines of their research, to the industry they were working in. However, their jobs did not necessarily match their qualifications. One group were carrying out jobs that were within their research fields and for which a PhD degree was a requirement. A second group, though working in similar fields to their areas of study, explained that those jobs could equally well have been performed by people with a Master's degree in the same field, indicating that a PhD was not always an essential requirement for the specific job in industry. Another set were engaged in related research industries where they applied theories, methodologies and tools similar to those they used during their studies, although to very different concepts and contexts. Yet another set attributed the relevance of having a PhD to the skills they acquired and not necessarily the subject they studied. This implied that, even in unrelated fields, some generic skills acquired during their studies proved useful (see also Appendix B).

4 Empirical findings

4.1 The role of networks in the 'academia-to-industry' transition

In the process of moving to industry, networks seemed to play a more or less important role, depending on the disposition of the students at the time when they were looking for a job. With the end of their studies imminent, the student would begin to explore various life paths after obtaining a doctorate. It was apparent from our data that the search for a job position was mostly directed by their area of study. If positions were available, 'interesting' and provided a 'good overlap' with their interests, they would take advantage of the opportunity. An interplay between the personal network of informants and a more extended network of their associates was apparent. Interviewee NOR-2 explained this:

> Actually, when we visited these conferences, and sometimes it was a professor who was visiting, not me. [...] He presented my work and then [researchers in the audience] were saying that they were also dealing with the same problem. Then he gave me their numbers and I contacted them. [...] it was actually a mixture of my network together with the professor's network. (NOR-2)

4.1.1 Personal networks

The personal network refers to links that were individually known to informants and that might enable them to transition into industry without having to tap into the network of someone else in their wider network. This included networks initiated during the PhD, as well as network ties that were established during prior work experience. In some instances, relying on personal networks was evident, as in the following instance:

> In that sense I had a collaboration with them but I applied [for the job]. I didn't really apply for a job. I guess I found a person whom I started talking to and then they ended up offering me a job. (SWE-07)

This was observed both in the case of collaborative (research carried out with industry partners) and non-collaborative doctoral studies. These personal network connections were seen to consist of either industry or academic contacts. Apart from existing connections (academia or industry), the graduates were also found to have initiated new connections that led to employment in industry. These links extended beyond the period of PhD education to include links such as colleagues from previous education. As UK-5 put it:

> I had a colleague from London South Bank, where I did my Master's, who was the technical manager in that area. When I was in the UK looking for a job opportunity, I contacted my colleagues, and she gave me the opportunity. (UK-5)

4.1.2 Extended networks

Additionally, we isolated an external network of wider university and industry connections that played unique roles in the graduates' industry employability. This was mostly evident when a personal connection of the graduate referred them to another person to increase their job prospects. Some PhD graduates were, however, reluctant to use the network of fellow academics and preferred to rely on their own network, as NOR-4 explained:

> I would not use it [the network built during the PhD] for finding jobs but it will be more on the technical side [for exchange of knowledge] (NOR-4)

Our data showed that academic supervisors or principal investigators (PIs) rarely played a direct or active role in the transition to industry. The participation of PhD supervisors was peripheral and they were often relegated to the role of a referee in the recruitment process. Only in two cases did a collaboration initiated by a PI lead to the recruitment of his PhD student:

> ... he went to my university ... he told my supervisor and then my supervisor got me to go for their interview (UK-9)

. In the other cases where help had been sought from supervisors, the opportunities within the PIs' network were seemingly non-existent.

Further, none of our informants reported any specific help from their universities in transitioning into an industry job. However, belonging to a research group that had enjoyed some collaborations with industry gave access to some research-relevant industries:

> (Interviewee) On paper, [my PhD] was in coordination with Saab, I had quite some things with them to do, from my personal viewpoint I would say nothing of what I've been studying has been applied [laughs], so there must be a total failure somewhere, but, yes, I mean, it was one of those [. . .] national research programmes, so normally it was partnership but...
> (Researcher) So you worked with people at Saab but not the ones that were involved in your recruitment?
> (Interviewee) No I didn't work with them, I worked with two guys maybe, but not that much. But I've been encountering some later but we never really worked together; but they all know what I've been doing. (SWE-12)

On the wider university scale, various platforms also provided an opportunity to meet industry employers. In the case of one interviewee, it was an event organized by a student association that was decisive in starting the transition to industry: *"And so it was very informal. I happened to meet an HR person at a dinner about a year earlier"* (SWE-7).

4.2 Outcome of network-aided transitions

In some of the instances where networks were the mechanism through which the transition to industry occurred, positions were 'created' for the doctorate holders. In this way, networks not only facilitated the transition to industry but also influenced the outcome of the process.

> The position was there [but] it was not meant to be a position for my scope. When I applied, then they felt that they also need to have someone with my background and my experience, that they made some adjustment in the requirements of the vacant position. (NOR-5)

Most of the PhDs maintained their academic network when transitioning to industry. In some cases, this was more social in nature, while in other cases there was also academic content, in the form of part-time academic positions and/or co-publication relationships. Some of the PhDs may have maintained this academic involvement because they believed it might increase their chances of moving back to academia at a later stage of their career.

Overall, the kinds of network ties and their importance for the transition of PhD graduates to industry varied considerably. Personal networks were more prominent than extended networks. Individuals took advantage of their existing networks or forged new ties. Depending on their particular interests, they used both explorative and exploitative means to aid their job search. The various channels that emerged from our analysis are summarized in Table F.2.

Table F.2: Network-aided transitions of doctorate holders from academia into industry.

	Personal Networks	**Extended Networks**
New ties	Individual's attitude to searching and preferences - Exploration - Exploitation	PIs' networks Research group links Wider university links Industry links
Existing ties	Formed before, during or after PhD education	

4.3 Inter-regional mobility

The search for an industry job resulted in half of the informants (15 out of 31) leaving the region (or country) where they obtained their doctorates. Also, we see this distinction in mobility, with graduates in Scandinavia more likely to stay in the region, whereas most graduates in the UK moved to obtain employment. Although these findings are in line with the higher labour mobility in the UK than in Scandinavia, the differences could also be explained by the fact that the UK PhD graduates had already moved before – which is understood to increase the likelihood of moving again. The UK graduates themselves mainly ascribed their reason for moving to a lack of employment opportunities in the region of study. In these cases, they could not see a regional career path before them and were more inclined to fall back on industry or academic networks built before, during or after their PhD. This was highlighted by UK-4:

> To be honest, that time I did not get any opportunity in my field and there was no vacancy actually. But, if I got any opportunity during that time .... because I was living there for four years we had some kind of social relationship with people and also we know lots of people there. It would have been good for us to stay there... I did my master from [anonymized university] before, so I already knew the place and that's why I came to [the same place] after my PhD. (UK-4)

One reason for the absence of relevant local network connections could be that the development of such a network is a long-term process and is hard to develop when starting from scratch as a newcomer to the region. The Sweden sample was characterized by nearly equal proportions of persons who left or stayed in their respective regions. With a very high exposure to industry during the PhD, the tendency was to access these industry contacts for their transition, as in the case of SWE-9:

> [My first job in industry] was very tightly connected to my PhD project. The company I work for now, they were the main sponsor of that project. But I was not an industrial PhD, so I was employed completely by the university. [...] basically, they asked me if I wanted to work there [after my PhD]. (SWE-9)

To that extent, a regional career path was visible. Additionally, the majority of informants were likely to transition into industry after some time working as a post-doc in academia. In our Norway sample, a regional academic path was prominent. Pre-PhD industry networks seemed to be highly influential on the career moves and nearly all interviewees remained in the regions where they had received their PhD education. However, personal factors related to family also drove their mobility.

Most of the PhDs in Norway and Sweden were familiar with their respective regions before entering their PhD position, while majority of the interviewees from the UK migrated for study purposes, having kept more of an open mind with respect to the geographical location of PhD programmes. Interviewee NOR-10 explained how his existing network in his region helped him land his PhD position:

> I was actually based here when the position was advertised and I knew one of the people from the companies who were sponsoring the [research centre]. I actually came to know about the position through him. He happened to be one of the interviewers from my previous company where I was working in Stavanger. I got the job in that previous company because of him, then he moved out and then we met and then he suggested that the sector has been just established and they're going to post position for many PhDs. (NOR-10)

With regard to the motivations to study at the various institutions, the interviewees fell into two main groups: first, those interested in studying at a particular university and, second, those who were more interested in a field of research than in the university that offered it, as emphasized by UK-2: *'I would be lying to say it was the place. ... .I liked the project, it sounded cool and I was accepted.'* Specifically, for those interviewees who knew from the start that they would opt for an industry career post-PhD, the location of the university appeared to be important – if the industries of interest were accessible.

4.4 Country specificities of network-aided transitions

Our data reveal country-specific dominant patterns, in terms of the characteristics and tendencies of university-to-industry career transition, as follows:

- In Sweden, doing a post-doc was quite common; and PhDs' academic networks seemed to drive the academic career vertically. However, a prolonged stay in academia weakened the ties to pre-PhD industry networks. Overall, PhD students have a relatively high exposure to industry and their industry networks once they graduate are mostly different from their pre-PhD industry networks. Finally, regional career paths are quite noticeable.
- In the UK, a post-doc is seen more as an option than as a preference. Individuals' academic and industrial networks change markedly before, during and after the PhD, owing to quite high geographical mobility. If students are exposed to industry during their PhD studies, this has a significant impact on transferable skills, and the existence of a firm-centred OILM during PhD education often functions as a network mechanism for post-PhD careers.
- In Norway, choosing a post-doctoral contract is less common than in Sweden. PhDs' industrial networks built before they embark on their doctoral studies seem to have an important influence on their career moves. Working in industry after gaining a Master's but before starting PhD studies is quite common. However, exposure to industry during the PhD does not seem to be that high. Regional career paths are noticeable. Nevertheless, it is worth highlighting that most of the PhDs in the Norwegian sample may have been affected by the recent downturn in the oil industry, disrupting the observed transition model; that is, some students who had worked in industry prior to the PhD and chose to return to further study when they lost their jobs. Finally, the existence of a firm-centred OILM prior to the PhD often functions as a network mechanism for post-PhD careers.

Figure F.2 schematically summarizes the above-mentioned country-specific trends in a model based on Lam's (2007) OILM framework.

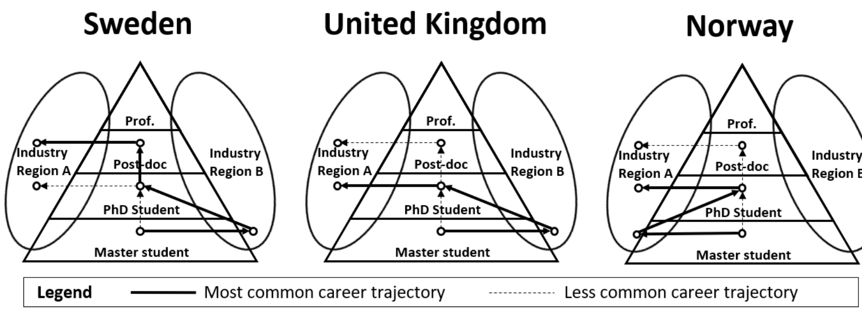

Figure F.2: Country-specific patterns of transition of doctorate holders into industry.

5 Discussion

From our observations, it is evident that different types of networks come into play in the industry employability of PhD graduates. First, the personal network connections of the PhD graduates were important, both in the case of collaborative and non-collaborative PhDs. By 'personal network', we refer to the graduates' own links that directly led to employment in industry. These personal network connections were observed to consist of either industry or academic contacts with whom the graduate had existing connections prior to job search, and extended beyond the period of PhD education (e.g. where previous colleagues from Master's programmes played a role in their landing employment).

Apart from their pre-existing connections, the graduates also initiated new connections that led to employment in industry. Contrary to Mangematin's (2000) observation that PhDs generally do not possess the requisite networks or experience to explore non-academic options, it is clear from our research that certain PhD graduates not only have the requisite networks but also initiate the necessary connections and may actually prefer to rely on their personal networks. Future research could explore whether this could be linked to the emphasis put on networking skills in doctoral education in the past decade.

Second, there was evidently an external network of wider university and industry connections who could also play unique roles in finding jobs in industry for graduates. In either case, the network tie could be a new or an existing connection in the graduate's network.

According to Lam (2007, 2011), professors, post-docs and PhD students fulfil their distinct roles at the university–industry interface. While professors are conceptualized as the focal points of these links, post-docs and doctoral students are considered the 'growing' and 'hybrid' categories of linked scientists. Thus, although professors play a central role in this area, evidence suggests that their influence in the employability of the PhD graduates in industry is peripheral. Accordingly, it has been reported that professors – or PIs – often lack the networks in industry that could contribute to industry employment of their students. Indeed, they usually lack knowledge of career opportunities that may exist in industry (Golde, 2005). As our data showed, their role in many cases was confined to providing references to support their students' job applications.

It has been suggested that the increasing blurring of university–industry boundaries as a result of collaborations (Thune, 2009; Roberts, 2018; Benito & Romera, 2013) is likely to yield more job opportunities for PhDs in industry. In particular, university–industry collaborations may serve as a platform for the selection, screening and subsequent recruitment of PhD graduates into firms (Lam, 2007). In that case, it would be expected that PhD graduates who were involved in collaborative projects (for their PhD studies) enjoy a smoother transition to industry employment, especially if facilitated by PIs. This is, however, not explicitly observed from our evidence. For example, the transition to industry of both groups of PhD graduates (from non-collaborative and collaborative PhDs) was not facilitated by PIs.

According to Hancock and Walsh (Hancock & Walsh, 2016), doing a PhD may mean forgoing other training opportunities relevant for non-academic jobs. Similarly, we found that in many cases the PhD qualifications are indeed more field-specific than industry jobs would require. Industry opportunities tend to assume a not-too-specific nature and do not necessarily call for highly specialized scientists. We suggest that this creates a mismatch that the extended university–industry networks cannot always overcome. Contrary to Hancock and Walsh's observation, though, we also find that the PhD education actually equips graduates with other industry-relevant skills. When they are employed in industry, they offer an edge, not necessarily the merits of a field-specific PhD qualification but a wider set of qualifications and skills, such as those related to management. In cases where hiring is based on the field-specific expertise of the graduates, the creation of new roles is observed. Moreover, PhD degrees are often not a 'necessity' for industry work (see Appendix B) but are sometimes useful for work progression once hired, or may lead to the creation of new roles and positions in companies.

The dynamic nature of doctoral candidates' attitudes and interests needs to be considered too. Individuals who pursue a PhD reportedly have a taste for science and those who lose interest in research during their studies are more likely to pursue industry jobs (Sauermann & Roach, 2012; Hayter & Parker, 2019). While this change in career preference is evident from our study, the destination of PhD graduates (i.e. industry or academia) is also subject to whether they adopt an 'exploration' or 'exploitation' mode with regard to opportunities. With the increasingly low likelihood of acquiring academic jobs, non-academic destinations are not simply a preference but a necessity for the PhD holder. In such cases, the absence of existing networks to exploit – as the candidate's current networks may be mainly of an academic nature – leads to an exploration of new opportunities by initiating the establishment of networks with industry.

6 Conclusion

The concept of OILMs was employed to explain the way in which doctoral graduates benefit from the extended networks of academics around them in making the career transition to industry. The findings from the study indicate that, in the academic labour market too, networks play an important role in facilitating labour market matching processes. The interview data demonstrate that OILMs, when seen from the academic side of the network, play a rather peripheral role in facilitating the career transition of doctoral graduates. On the other hand, from the industry side of the network, OILMs, in the form of connections with individuals in industry known to graduates from their networks established before or during their studies, do play a positive role in their transition from academia. What our study shows, therefore, is that the personal networks of doctoral graduates intertwine with university–industry OILMs, which can facilitate a move to industry

Nevertheless, contextual specifics make a difference with regard to the extent to which personal networks of doctoral graduates overshadow the OILMs. In a context like the UK, where the mobility of doctoral applicants and graduates is very high, the personal networks were sparse, making it less probable that such networks intertwine with OILMs around the graduates' university. On the other hand, in a context such as Norway, the geographical closeness of the pre-PhD and through-PhD personal and professional networks of graduates helped them considerably to intertwine those networks with the OILMs, which were in fact mainly formed between their pre-PhD employers and their alma mater. In the case of the Swedish interviewees, personal and professional networks became updated during their studies, forming an OILM that later was used for the transition to industry.

Overall, there seems to be a meaningful level of relationship between doctoral graduates' history of geographical mobility and the extent to which they exploit OILMs. Our data show that, the less the geographical mobility during the pre-PhD and post-PhD periods, the greater is the likelihood of benefiting from the intertwining of personal networks with the OILMs. Nevertheless, regional job market characteristics condition the above statement. As our Norwegian cases show, the possibility of formation of OILMs between university and industry is largely influenced by the industrial structure of the region where the university is located. These observations corroborate the findings in the literature on job (mis)match and spatial mobility, which indicate that *'geographical characteristics are likely to affect labour market outcomes such as match or over-education'* (Iammarino & Marinelli, 2015, p.2). We conclude that university–industry OILMs can help facilitate the transition of doctoral graduates to industry when graduates actively explore such spaces through their personal networks, but regional industrial characteristics also significantly influence the intensity of OILMs and hence the OILMs' potential usefulness for job searching and matching.

This paper contributes to the literature on university graduates' career paths, specifically those of doctoral graduates, as well as the role of social (and professional) networks in job matching. Using the concept of OILMs made it possible for us to combine and establish a link between these strands in the literature. The findings of our study are aligned with Thune (2009), who, based on a review of empirical literature on graduate student–industry collaboration, asserted that it is predominantly the individual characteristics of doctoral graduates, rather than the their collaborative experiences during their PhD education, that can explain differences in their career trajectories. In a similar vein, our analysis made it clear that the OILMs, while providing a structure for exploring career transition opportunities, do rely on the agency of these job seekers to actualize and deliver their potential. In other words, it is when the candidates activate their own networks and intertwine them with the networks taking shape within OILMs that university–industry extended networks (extended internal labour markets) function best in terms of facilitating a career transition. At the same time, however, the contextual factors such as the industrial structure of the region where the universities are located and the degree of interaction between university and industry influence the OILMs' potential for enriching agents' individual networking initiatives.

A practical implication from these results is directed at doctoral researchers and graduates who seek to pursue a career in industry after doctoral education. As indicated above, there seems to be a significant role attached to the agency or, in other words, the deliberate and conscious initiative of the doctoral graduates in activating the potential of university–industry extended networks (OILMs) is key to their success in finding a job in industry and successfully transitioning to it. Also, a policy implication relating to collaborative doctoral programmes can be drawn from our observations. In order for such programmes to deliver more career-relevant results, it seems to be essential to design and structure the collaboration terms in such a way as to maximize the networking opportunities for students. Our observations showed that the firm side of OILMs play a more influential part in providing career-relevant networking opportunities than the academic side.

The findings of our study need to be understood with certain limitations in mind. University–industry OILMs are not formed solely in the STEM fields, although they may take shape more clearly in these fields. Hence, further research might explore whether our findings apply to doctoral graduates from other academic disciplines. Furthermore, our cases were limited to a sample of doctoral graduates from a few universities in the UK, Sweden and Norway. The importance and the functioning of personal networks can change based on the size of informal networks (cf. Calvó-Armengol and Zenou (2005)) and their influence in finding a job in different countries and cultures. Accordingly, further research is needed to look into the relevance of OILMs for the job transition of doctorate holders from other geographical and cultural contexts.

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A Interview guide

Table F.3: Interview Guide.

Theme	Question	Purpose
Demographics	Age; the time when the PhD was completed; field of study/research;Is present work related to field of study?	To understand the background
Current job	Describe in a few words your current job; Is there any link with your PhD?; Are your PhD studies useful for your current job? How?; Was your PhD an industrial PhD?; Do you speak the local language?	To understand the background

Continuation of Table F.3

Theme	**Question**	**Purpose**
Path to industry	When did you graduate (PhD)?; When did you leave academia for industry?; Have you always wanted to work in industry?; This kind of industry? Why? ; If changed? Why? (who and what influenced it?; How did the influence happen?); Did you work in industry prior to your Phd?; Have they returned to the same or similar industry?; No - What/who could have influenced a change in industry?; Yes- How has the PhD influenced your work now that you are more educated?; How did you find your job (the one of transition)?	Historical footprints could have an effect on a person's decisions; To see if will / inspiration comes from someone in particular (thus from network) or not; To see if network was built prior to the PhD
Prior connections	Did your job exist or was it created for you?;Were you referred to this job?; Did you know anyone in your job prior to the appointment? How? Who?; Did you know this person during your Phd?; Did your PhD supervisor (or any academic) play a role in this transition?	Influence of network on landing industry employment (connections to people, places and institutions)
Feedback loop	Would you want to go back to Academia?; Why?; Who in academia have you remained in contact with? (why?)	To get the interviewee to be reflective, assess influences, etc.
Network	Have you built your network during your PhD studies or before?; What type of network? (academia, industry); Is your network the same as your supervisor's?; Do you still use the network you built during your PhD studies?; Do you think it could be useful to find a job?; How?	To understand the background + To get the interviewee to be reflective, assess influences, etc.

Continuation of Table F.3

Theme	Question	Purpose
Region	Why did you choose [university] for your PhD?; Why did you leave [stay in] the region after the PhD?; Would you have liked to stay in [leave] the region?; Were there job opportunities for you in the region?; If you had been referred to a position in the region, would you have accepted it instead of your current job?	To understand the background + To get the interviewee to be reflective, assess influences, etc.

B Perceived relevance of PhD Studies to industry jobs

Table F.4: Perceived relevance of PhD Studies to industry jobs.

Variants Observed	Relevance of PhD to job	Area of relevance	Required PhD degree
1	Yes	Same research field	Yes
2	Yes	Same research field	No
3	Yes	Related research field	Yes
4	Yes	Related research field	No
5	Yes	Different research field (skills acquired from PhD relevant)	No

SUMMARY

The relevance of the university as centuries-old institution has been renewed with the rise of the knowledge-based economy. Through interaction with their environment via a variety of channels universities can have an impact on their region by providing both public and private actors access to knowledge and requisite human capital. This thesis provides insight in how this impact can be realised through the university-industry knowledge transfer channels of graduate human capital and research collaborations by answering the following question:

What is the role of university–industry research collaborations and graduate production for the impact of universities on regional industrial development?

The insights are based on analyses of Danish micro-level data, Community Innovation Survey data, interview data, and other data using a variety of empirical techniques. The results highlight the importance of universities alignment with regional industries for fostering its ability to contribute to the regional industrial development. Furthermore, it argues for taking a comprehensive approach to the university-industry knowledge transfer channels, as the utilisation of potential synergies between human capital production and research collaborations can increase their impact on regional industrial development.

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