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BY
DAVID FERNÁNDEZ GUERRERO

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AALBORG UNIVERSITY
DENMARK

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Publications

- Guerrero, D.F., 2020. *Industry–university collaboration in rural and metropolitan regions: What is the role of graduate employment and external non-university knowledge?* Journal of Rural Studies, Special Issue on Innovation in Peripheries and Borderlands (In Press, Corrected Proof). DOI: 10.1016/j.jrurstud.2020.03.007

- 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 a book on The Role of Universities in Regional Development and Innovation.

ENGLISH SUMMARY

Since the 1980s, policymakers have promoted universities' involvement in regional economic development. Increasingly since then, universities have been incentivised to develop a range of third-mission activities to transfer their knowledge to local firms, adapting their educational and research activities to support innovation in regional firms in the process. At the same time, increasing regional disparities in innovative activity and economic development suggest that policies promoting collaboration between universities and regional firms should be suited to different types of regions; factors that are relevant to industry–university collaboration in one type of region might not be as relevant in another type of region. Thus, the present thesis addresses the following research question:

To what extent do the roles of key factors associated with university–industry collaboration differ across types of regions?

This thesis includes a synopsis and four papers; pointing to a range of factors whose roles in industry–university collaboration vary across different types of regions. The thesis suggests that the positive association between firms' employment of university graduates and industry-university collaboration is stronger among firms in rural regions than among firms in other types of regions; the knowledge of university research that is provided by graduate employees allows firms in rural/peripheral regions to collaborate with universities, despite being farther away from universities than are firms in more densely populated regions. Also, certain forms of external knowledge sourcing—firms' collaboration with research and technology organisations—appear less likely to be related with industry–university collaboration among firms in non-metropolitan regions that are home to universities compared to firms in other types of regions. Among firms in such regions, however, the desire to satisfy international customers incentivises them to develop their links with universities into collaborative research. Universities in non-metropolitan regions are also key actors in the establishment of industry–university links; these universities do so by supporting the development of new industries, and by approaching new SME partners in their home regions.

These findings have the potential to inspire a range of policy actions. On the university side, policies that provide financial support to non-metropolitan universities' regional engagement activities can further incentivise their inclination to devote educational, research and third-mission activities to regional development. On the firm side, policies should be designed with an eye on the incentives and goals of firms in different types of regions when starting and developing collaborations with universities. Based on the findings, it is possible to point to existing schemes that could be suited to increase the incentives of firms in rural regions for collaborating with universities. These policies would include increased financial incentives to firms

in rural regions that wish to hire university graduates, and to firms in rural regions that wish to purchase research services from universities and RTOs.

DANSK RESUME

Siden 1980'erne har der været fokus på at fremme universiteternes engagement i regional økonomisk udvikling. Siden da har universiteterne fået flere incitamenter til at udvikle tredje–missions-aktiviteter rettet mod vidensoverførsel til lokale virksomheder og tilpasning af deres uddannelses- og forskningsaktiviteter med henblik på at understøtte innovation i regionale virksomheder. Samtidig indikerer stigende regionale forskelle i innovationsaktivitet og økonomisk udvikling, at tiltag, der fremmer samarbejde mellem universiteter og regionale virksomheder, bør tilpasses til forskellige typer af regioner: faktorer, der er relevante for industri-universitets-samarbejde i én type region, er ikke nødvendigvis lige så relevante i en anden type region. Derfor undersøger nærværende afhandling følgende forskningsspørgsmål:

I hvilket omfang varierer centrale faktorers betydning for industri-universitets-samarbejde mellem forskellige mellem typer af regioner?

Denne afhandling omfatter en kappe og fire artikler; der analyserer en række faktorer, hvis rolle i relation til industri-universitets-samarbejde varierer på tværs af forskellige typer regioner. Afhandlingen indikerer, at den positive forbindelse mellem virksomheders ansættelse af universitetsuddannede medarbejdere og industri-universitets-samarbejde er stærkere for virksomheder beliggende i landdistrikter end for virksomheder i andre regioner. Den viden om universitetsforskning, som medarbejdere med en universitetsgrad besidder, giver virksomheder i landdistrikter / perifere regioner mulighed for at samarbejde med universiteter, på trods af at de er beliggende længere væk fra universiteterne end virksomheder i mere tætbefolkede regioner. Desuden peger afhandlingen på, at samarbejde med teknologiske serviceinstitutter blandt virksomheder beliggende i universitetsregioner uden for de allerstørste byer i mindre grad er forbundet med industri-universitets-samarbejde sammenlignet med virksomheder i beliggende andre typer af regioner. Blandt virksomheder beliggende i universitetsregioner uden for de allerstørste byer kan ønsket om at imødekomme behov fra internationale kunder være en stimulerende faktor bag udvikling af forskningssamarbejder med universiteter. Universiteter beliggende i ikke-storbyregioner er også nøgleaktører i forbindelse med at etablere relationer mellem industri og universitet. Dette gør de gennem at understøtte udviklingen af nye industrier og gennem opsøgende arbejde overfor nye SMV-samarbejdspartnere i hjemregionen.

Afhandlingens resultater kan inspirere policy. Set fra universiteternes side kan tiltag, der yder økonomisk støtte til opsøgende aktiviteter udført af universiteter beliggende uden for storbyregioner give yderligere incitamenter til at dedikere uddannelses-, forsknings- og tredje-mission aktiviteter til at understøtte den regionale udvikling. På virksomhedssiden bør tiltag udformes med øje for de incitamenter til og målsætninger med at etablere og udvikle samarbejder med universiteter, som for virksomheder

beliggende uden for storbyregioner har. Med afsæt i resultaterne er det muligt at identificere eksisterende tiltag, der kan bidrage til øge incitamenterne for at virksomheder i landdistrikter samarbejder med universiteter. Sådanne tiltag omfatter øgede økonomiske incitamenter til virksomheder i landdistrikter, der henholdsvis ønsker at ansætte universitetsuddannede og købe forskningstjenester fra universiteter og teknologiske serviceinstitutter.

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When I started the present thesis, one of my loved ones—who, I leave it to him/her—warned me against believing that the thesis would be a nice, easy motorway. Rather, it would look more like a bumpy rally around the countryside with its setbacks, its changes of plans… these detours are, however, what made of the thesis journey a deep learning experience. So, no regrets. If anything, my feelings can boil down to a mixture of satisfaction for the journey done, nostalgia for what I have experienced, and gratitude for the immense help and support I have received from supervisors, colleagues and friends.

The list of persons to be mentioned is massive, but one of them stands clearly over the others; Ina Drejer, my supervisor at Aalborg University. Along the thesis journey, she has been a thorough, patient source of advice. She has dedicated countless hours to review multiple versions of each thesis paper; an effort that I will make sure it pays off. She has also been a crucial shoulder whenever the obstacles to overcome appeared to be insurmountable. Her effort has been essential in improving my strengths as a researcher, in particular my ability to boil down abstract concepts into language intelligible for other human beings—researchers or not—; and my ability to prioritise the most essential tasks at the expense of those that "*would be nice, but not necessary*". After all, detours in the research journey provide plenty of learning, but one can get lost if following them in excess. Along the same lines, thanks are also due to Christian Richter Østergaard (Aalborg University). His advice in simplifying what were long, difficult to understand arguments proved crucial in moments of need; and his cookies and cakes provided an extremely convenient energy boost, after taxing presentations.

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I also recall the colleagues and friends that I have met at courses, workshops, conferences; in meetings like these one can truly benefit from being at the shoulders of giants, and learn. Outside what is strictly my academic community, I am also grateful to all the researchers and firm managers that have contributed to my fieldwork, either as gatekeepers or as interview participants.

Last but not least, I am infinitely grateful to my family, friends—in Aalborg and in Catalonia—, and my partner. Their patience, company and emotional support has been crucial to raising my mood; and in reminding me why I signed up for the PhD journey.

David Fernández Guerrero

Barcelona, May 2020

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THESIS DETAILS

Thesis Title: Industry-university collaboration in different types of regions: The role played by non-metropolitan university actions, graduate employment and external knowledge sourcing in industry-university collaboration

PhD Student: David Fernández Guerrero

Supervisor: Professor Ina Drejer, Aalborg University

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

A) 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 RUNIN Book on The Role of Universities in Regional Innovation and Development[1].

B) Guerrero, D.F., 2020. Industry–University Collaboration in Rural and Metropolitan Regions: What is the Role of Graduate Employment and External Non-university Knowledge? Journal of Rural Studies. https://doi.org/10.1016/j.jrurstud.2020.03.007

C) Guerrero, D.F., 2020. Bridging the Gap between Firms and Universities: Firm Links with Research and Technology Organisations in Different Types of Regions, RUNIN Working paper series 03/2020. https://doi.org/10.3990/4.2535-5686.2020.03

D) Guerrero, D.F., 2020. SME-University Collaboration in Non-metropolitan regions: A Multiple Case study Analysis of How Collaborations Start and Unfold, RUNIN Working paper series 04/2020. https://doi.org/10.3990/4.2535-5686.2020.04

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. As part of the assessment, a co-author statement has been made available to the assessment committee.

[1] Cited in the thesis in its working paper version, publicly available:

Guerrero, D.F., Evers, G., 2018. Co-creation of Localised Capabilities between Universities and Nascent Industries: The Case of Aalborg University and the North Denmark Region (No. 03/2018), RUNIN Working Paper Series. https://doi.org/10.3990/4.2535-5686.2018.03

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PART I: SYNOPSIS

CHAPTER 1. INTRODUCTION

1.1. MAIN OBJECTIVE AND MOTIVATION

This endeavour started with a curiosity and a concern. Economic development in most southern European regions is still lagging behind that of their northern European counterparts, despite years of participation in the European project (Iammarino et al., 2017). As a southern European, I was curious about what insights could be gained from the geography of innovation field and that could be used to understand and improve the regional innovation and development policies applied in the part of the world I come from. In addition, I was concerned about the consequences that the geographical unevenness of innovation and economic development could carry outside metropolitan centres. I could see how the world was becoming increasingly spiky (Rodríguez-Pose and Fitjar, 2013), with innovation and economic development concentrating around a few (mostly metropolitan) spots. I could also sense that an increasingly spiky world might come at the price of diminished economic opportunities for those regions located outside metropolitan centres like London, Copenhagen, Lisbon or Barcelona. Indeed, an expanding literature pointed to decreasing economic opportunities and out-migration from rural settlements and old industrial districts because they lack some of the factors that can facilitate innovation, such as access to global knowledge pipelines (Isaksen and Trippl, 2017; 2014; Jauhiainen and Moilanen, 2012; Rodríguez-Pose and Fitjar, 2013; Shearmur and Bonnet, 2011; Tödtling and Trippl, 2005). This concern is also visible in EU policy documents (ESPON, 2017; Iammarino et al., 2017). Furthermore, these developments were leaving a trace of social unrest and political instability in regions located outside metropolitan centres, or what Andrés Rodríguez-Pose (2018) has called the revenge of the places that don't matter.

Thus, my participation as a PhD researcher in the RUNIN (Role of Universities in Innovation and regional development) training network offered a formidable opportunity to satisfy my curiosity and to try to contribute to a better understanding of how innovation and development could be stimulated in non-metropolitan regions, particularly among those that had more grounds to be considered part of the economic, demographic and/or geographic periphery (Eder, 2019). Universities have, for years, been tasked with the mission of supporting innovation and development in their local regions (Boucher et al., 2003; Charles, 2006; Drucker and Goldstein, 2007). Businesses' innovation efforts have been argued to benefit from the presence of universities in their regions, owing to personal interactions with university researchers and the communication of tacit knowledge (Audretsch and Feldman, 1996; D'Este and Iammarino, 2010; Feldman and Florida, 1994; Jaffe et al., 1993). At the same time, most of the literature has explored what factors are positively associated with industry–university collaboration, independent of the type of region where the firm is

located (Bruneel et al., 2010; D'Este and Iammarino, 2010; Laursen and Salter, 2004; Mohnen and Hoareau, 2003; Segarra-Blasco and Arauzo-Carod, 2008).

Similar proportions of firms collaborate with universities inside and outside metropolitan regions, at least in Denmark and Norway (Drejer et al., 2014; Jakobsen and Lorentzen, 2015). However, previous research suggests that there might be regional differences in how industry–university collaboration takes place. Compared to firms in metropolitan regions, those in non-metropolitan regions with no or few universities collaborate with university partners located farther away (Johnston and Huggins, 2016). Whereas metropolitan regions are home to multiple universities (Tödtling and Trippl, 2005), non-metropolitan regions are likely to contain a single campus, often regarded by the local firm community as a key innovation partner (Boucher et al., 2003). Compared to metropolitan regions, a larger proportion of firms in non-metropolitan areas tends to operate in sectors traditionally unlikely to collaborate with universities (Asheim and Coenen, 2005; Tödtling and Trippl, 2015). Thus, the main research question in the thesis intends to explore how the role of factors related to industry-university collaboration varies with regional location:

To what extent do the roles of key factors associated with industry–university collaboration differ across types of regions?

By answering this, this doctoral thesis aims at contributing to the industry–university collaboration literature with an improved understanding of the relationship between factors associated with industry–university collaboration and the type of region where firms are located. In addition, the findings from this project may also be useful to policymakers. An improved understanding of industry–university collaboration across regions can support policies aimed at improving the role that universities play in supporting innovation and development in different types of regions. In particular, this thesis will offer insights useful to policymakers interested in enhancing these activities in non-metropolitan regions. Given the considerable expectations put on the shoulders of universities as drivers of innovation and growth in non-metropolitan areas (Boucher et al., 2003; Nilsson, 2006), any findings that contribute to fine tune their third-mission efforts could be of use to policymakers.

The rest of the synopsis includes a review of the conceptual framework and the specification of the main research question into specific sub-questions. Then, I offer an overview of the thesis papers and their links to the research sub-questions. Next, I discuss the empirical settings and describe the data sources and research methods used. The last section outlines the main contributions of the thesis to the literature, and to policies.

1.2. CONCEPTUAL SETTING

This section outlines the main streams of literature and concepts leading to the research sub-questions. First, I discuss how the geography of innovation's literature understanding of innovation has evolved over recent decades, and how this literature helps us to comprehend innovation in different regional settings. A section will follow, on the geographical classifications of regions used in the present thesis. Next, the research on external knowledge sourcing and its interplay with regional location is reviewed. This is followed by a discussion of factors associated with industry–university collaboration and different conceptualisations of universities' third mission. Finally, I conclude by combining the insights from the literatures on industry–university collaboration and geography of innovation and formulate the research sub-questions.

1.2.1. GEOGRAPHY OF INNOVATION, AND ITS FOUNDATIONS

The geography of innovation field covers a range of literature streams, such as those on economic geography (Audretsch and Feldman, 1996; Bathelt et al., 2004; Boschma, 2005; Feldman and Florida, 1994; Jaffe et al., 1993; Storper and Venables, 2004) and regional innovation systems (Asheim et al., 2011; Asheim and Coenen, 2005; Cooke, 1998; Tödtling and Trippl, 2005).

These literature streams take inspiration from the idea that new knowledge tends to be difficult to codify and has a tacit component. Accordingly, it is best transmitted at short distances, through face-to-face exchanges. With this idea in mind, a number of publications suggested that firms in geographical proximity to knowledge sources such as universities, research institutes, company R&D departments or university-trained professionals would be able to benefit from knowledge spillovers, because geographical proximity would enable continuous encounters with these knowledge sources (Audretsch and Feldman, 1996; Feldman and Florida, 1994; Jaffe et al., 1993). These arguments relate to the idea, proposed by Alfred Marshall, that information can flow among co-located firms within an industry because co-location facilitates the exchange of information among them (Marshall, 1920; Rosenthal and Strange, 2004). Other authors have criticised the notion that information flows freely in geographical proximity, arguing instead for pecuniary channels—contract research—and collaborative research as conduits of knowledge transmission (Breschi and Lissoni, 2001).

Also taking inspiration from the idea that geographical proximity enables the transmission of knowledge, and inspired by the insights from the National Innovation Systems (NIS) literature that interactive learning is key to innovation processes (Lundvall, 2016), those researchers working on Regional Innovation Systems (RIS)

see in the region a crucial scale in the innovation process (Asheim et al., 2011; Asheim and Coenen, 2005; Cooke, 1998; Tödtling and Trippl, 2005). Firms should be able to develop innovations by interacting with other actors in their region, such as universities, public research organisations, technology mediating organisations, customers or competitors; and different regional organisational endowments might be conducive to different innovative processes.

Since the inception of the RIS concept in the 1990s (Cooke, 1998), multiple interpretations have been developed. These interpretations share with the NIS literature the understanding of innovation as an interactive process; they have stimulated in regional policymaking a shift away from the linear understanding of innovation to policies promoting collaboration and knowledge exchange between firms and other actors in the RIS. As a result, there is a tendency to take into account system failures, in addition to market failures, in the design of regional innovation policies; that is, challenges preventing interactive learning within the innovation system as well as organisational-level incentives to invest in research and innovation (McCann and Ortega-Argilés, 2013).

The RIS concept owes to its elasticity (at least in part) its diffusion in regional innovation policy (Uyarra, 2009). Indeed, different definitions of RIS have facilitated the adoption of RIS frameworks in different types of regions (McCann and Ortega-Argilés, 2013; OECD, 2011; Uyarra, 2009). However, that elasticity has come at the cost of a lack of common standards for defining RIS and measuring the effectiveness of the policies designed to improve their performance (McCann and Ortega-Argilés, 2013). As Uyarra (2010) pointed out, there is also the risk that policymakers adopt ready-made, best-practice recipes of how RIS should look like, disregarding how the RIS framework could actually be implemented in their regions and that each region has specific organisational and institutional traits. The following paragraphs discuss how regions are conceptualised from the perspective of the RIS literature.

1.2.1.1 Knowledge base approach.

Depending on the predominant knowledge base of the region's firms, a RIS can be classified as based on a synthetic, analytical or symbolic knowledge base. Firms working with a synthetic knowledge base rely on tacit knowledge and interactive learning within and outside the firm to innovate; consequently, a RIS where the synthetic knowledge base is predominant will be based on interactions among firm networks, and exchanges with research institutions will tend to involve applied, rather than basic, research. RIS primarily based on analytic knowledge will tend to show the opposite picture, with firms' innovation based on codified knowledge and the application of theories stemming from academic research; consequently, firms will tend to apply, to a greater extent, basic research, and interactions with universities will

be relatively common. In RIS primarily based on symbolic knowledge, firms will share with their synthetic counterparts a relatively low propensity to interact with universities because innovations stemming from a symbolic knowledge base will mostly rely on experimentation in studios and among creative teams. Business innovation will mostly involve cultural products, rather than products based on the application of scientific knowledge (Asheim et al., 2011; Asheim and Coenen, 2005).

1.2.1.2 Governance approach.

The RIS concept proposed by Philip Cooke and his associates (Cooke, 2008; 2004; 1998; Cooke et al., 1997) differs from the previous classification in that the focus is placed on how different forms of innovation system governance interact at the regional level with the innovation strategies pursued by firms. Three modes of governance and innovation support are considered:

- *Grassroots*, that is mostly led and supported by local actors, such as local businesses, financial institutions or local governments, with little participation in the governance of the RIS by outside, supra-local actors.
- *Network*, where local actors' coordination is supplemented by more complex regional organisations aimed at enhancing the spaces that regional actors can use as discussion fora. A broader array of financial and research organisations supports firm innovation efforts, and local, regional and national government actors develop policies aimed at increasing the innovative capabilities of the RIS.
- *Dirigiste*, which is representative of top–down, national government-led development initiatives, such as the establishment of national research facilities. Businesses support of infrastructure is also mostly organised nationally.

This classification is combined with another threefold typology, focused on businesses' innovation strategies and the innovation networks sustained by them:

- *Localist*, where local, mostly SME, businesses cooperate for innovation without many linkages to extra-regional businesses. There is little involvement of research and technology organisations, other than private institutes.
- *Interactive*, characterised by a mixture of SMEs and large businesses, whether regionally-owned or extra-regional. These RIS are also defined by continuous interactions between firms and between the business community and research and technology institutions, whether public or private.
- *Globalised*, where global corporations are the main innovation actor. Local SMEs' access to innovation is likely to be limited to their participation in the

> supply chains orchestrated by global corporations; similarly, the activity of research and technology institutes, whether public or private, is bound to serve the needs of these corporations.

In focusing on governance and innovation support modes, and on firms' innovation strategies, this classification emphasises the role that institutions can play in the diffusion of knowledge and innovation within a RIS. Different governance styles in a RIS (e.g. interactions dominated by local businesses or by national public research institutes) are likely to come together with different types of cooperation practices, as well as the institutional arrangements supporting these cooperation practices. Emphasis is also placed on the range of organisations that a RIS can contain; the types of innovation networks that are dominant in a region are likely to be conditional on the businesses present there (whether owned regionally or extra-regionally; whether small or large), as well as the infrastructure of financial and research organisations that support them, whether public or private.

1.2.1.3 RIS thickness approach.

A third RIS classification is better suited than the others to understanding how innovation processes take place in RIS with a limited variety of organisations, such as those present outside metropolitan centres. This last classification focuses on how different levels of organisational and institutional thickness relate to the innovative capacity of regions. Originally part of the same concept, that is institutional thickness (Amin and Thrift, 1994), organisational and institutional thickness refers to two different, yet related, regional characteristics: In *institutionally* thicker regions, formal norms and informal conventions enable cooperation between organisations. In *organisationally* thicker regions, a greater number of organisations constitute the knowledge generation and diffusion subsystem (e.g. universities, public research organisations, technology mediating organisations) and the knowledge application and exploitation subsystem (e.g. customers, collaborators, competitors). Organisationally thicker regions are, in turn, divided depending on their internal diversity, that is the extent to which the organisations present in a RIS encompass different industries and technological paths (Trippl et al., 2015a; Zukauskaite et al., 2017). In organisationally thick and diversified RIS, such as those in metropolitan areas, a broad range of firms from different industries and supporting organisations broadens the potential technology paths and innovations that firms can develop. In organisationally thick and specialised RIS, such as those of old industrial regions, firms and their supporting organisations focus on a narrower range of industries, limiting the technology paths that firms can follow. Organisationally thick and specialised RIS, thus, face a potential ceiling for firm innovation unless new industries are developed in the region or extra-regional knowledge linkages bring about change in the industrial structure of the area. In organisationally thin RIS, such as those of

sparsely populated rural regions, the problems observed in old industrial districts are all the more accentuated: Firms are co-located with a narrower range of knowledge-generating and -exploiting organisations, and interactions with regional organisations might be insufficient to develop innovations. Consequently, extra-regional knowledge linkages might be even more essential to enable interactive learning and innovation (Isaksen and Trippl, 2017; Tödtling and Trippl, 2005; Trippl et al., 2018).

1.2.1.4 How RIS are conceptualised in the present thesis: Organisational thickness and diversity.

RIS researchers who are focused on organisational thickness and diversity (Trippl et al., 2015a; Zukauskaite et al., 2017) point to regional traits that can help us understand how innovation processes occur in regions that host a narrow variety of organisations. The organisationally thinner and less diversified a region is, the less conducive it might be for firm innovation. Firms that are co-located with a narrow range of organisations operating in a relatively limited variety of industries can, potentially, combine fewer types of knowledge; and fewer knowledge combinations enable a narrower range of innovations. Conversely, firms are more likely to combine different types of knowledge—and firm innovation is more likely—in regions that are organisationally thicker and where there is a wide variety of industries. The formal and informal norms present in an institutionally thick RIS can facilitate firm innovation, yet its organisational thickness and diversity are also seen as crucial by RIS researchers.

These views find their echo in the work of economic geographers. Departing from the idea that face-to-face interactions facilitated by geographical proximity might facilitate the transmission of tacit knowledge and innovation (Boschma, 2005; Storper and Venables, 2004), these researchers have suggested that firm innovation is more likely in regions that host industries with related competencies. This is because firms that draw knowledge from other organisations with related competencies can more easily apply the knowledge they acquire to their existing knowledge base (Boschma et al., 2014, 2009; Boschma and Frenken, 2011; Boschma and Iammarino, 2009). Thus, a firm might have fewer possibilities to incorporate knowledge from organisations with related competencies, the organisationally thinner and less diversified a region is.

Regions also differ in the extent to which they are endowed with highly skilled labour. Organisationally thick and diversified RIS, like metropolitan regions, are typically home to multinational firms and a variety of high technology industries, which makes them attractive to highly-skilled, university-trained professionals. Furthermore, university-trained professionals can be further attracted to metropolitan regions because of the abundance of their peers: Co-location with other university-trained

professionals can facilitate the formation of social networks and the learning of informal cues useful to career progression (Storper, 2018; Storper and Venables, 2004).

Similar to their RIS counterparts, economic geographers have pointed out that extra-regional connections might be key to enabling firms to access useful knowledge and to innovate the less diversified and organisationally thinner a region is. Starting with the concept of global knowledge pipelines (Bathelt et al., 2004), economic geographers have found evidence that extra-regional knowledge flows can provide regional firms with access to related competencies they can integrate into their knowledge base (Boschma et al., 2009; Boschma and Iammarino, 2009; Timmermans and Boschma, 2014); a growing strand of research suggests that extra-regional and international collaborations might be particularly crucial beyond metropolitan areas. These partnerships have been found to be key to innovation in the southwest of Norway (Fitjar and Rodríguez-Pose, 2011a) and in North Jutland, Denmark (Drejer and Vinding, 2007), regions that can be considered to have organisationally thick and specialised RIS. Extra-regional and international collaborations have also been important to organisationally thinner RIS in Norway, Finland and Austria (Isaksen and Karlsen, 2013; Isaksen and Trippl, 2017; Jakobsen and Lorentzen, 2015; Tödtling and Trippl, 2015); Sweden (Grillitsch and Nilsson, 2015) and Canada (Doloreux and Dionne, 2008; Shearmur and Doloreux, 2016). In organisationally thin RIS, linkages with groups outside the home region might provide firms with knowledge that is largely absent at home.

In discussing how firms innovate in different types of regions, economic geographers and RIS researchers have moved beyond the argument that geographical proximity facilitates the transmission of complex, tacit knowledge. As pointed out by Boschma (2005) and Aguiléra et al. (2012), firms tap into different types of proximity as part of their innovation processes. Geographical proximity might support cooperation and knowledge transmission between two organisations, but in no way is it necessary if these organisations are cognitively proximate; that is their knowledge bases are similar enough to facilitate the interpretation and integration of each other's knowledge. Similarly, organisational proximity—that is, the extent to which two or more parties share an organisational arrangement such as being part of an R&D network—can also be conducive to the transmission of knowledge. For instance, two organisations do not need to be co-located to transmit knowledge to each other if they are part of a network arrangement. Social proximity can also enable knowledge transmission between organisations without them being geographically proximate; through relationships of trust, organisations can commit the effort required to cooperate and exchange complex knowledge. Finally, institutional proximity can also support cooperation and knowledge transmission between organisations that are not co-located because sharing formal and informal norms helps organisations coordinate their actions.

Firms are more likely to be co-located with a broad range of organisations, the organisationally thicker and more diverse a RIS is (Trippl et al., 2015a; Zukauskaite et al., 2017). Therefore, geographical proximity can be seen as relatively conducive to learning and innovation in metropolitan regions; and in these regions, cognitive proximity can also be seen as relatively conducive to learning and innovation since firms are more likely to be co-located with organisations with similar enough knowledge bases. A firm in a metropolitan region can also learn from organisations beyond its home region, yet interactions with other organisations at home might also be conducive to learning and innovation.

At the same time, in an RIS that is organisationally thin—or organisationally thick, but specialised—, geographical proximity is unlikely to be conducive to learning and innovation, compared to an organisationally thick and diversified RIS. Meanwhile, other proximity types might be more conducive to learning and innovation. As shown by Boschma and Iammarino (2009), firms can tap into exchanges with organisations beyond their region to acquire knowledge related to their knowledge base; that is, they can tap into cognitive proximity. Other evidence supports this point, relating collaboration with extra-regional, and foreign organisations with innovation, in organisationally thin RIS and in organisationally thick, but not diversified, RIS (Drejer and Vinding, 2007; Isaksen and Karlsen, 2013; Isaksen and Trippl, 2017; Jakobsen and Lorentzen, 2015; Tödtling and Trippl, 2015). Indeed, the other forms of proximity might also contribute to learning and innovation, both in organisationally thick and organisationally thin RIS, as long as firms and other organisations share organisational arrangements, relationships of trust, or similar formal and informal norms.

Hence, there seems to be an emerging consensus among RIS researchers and economic geographers that organisational thinness is relevant, but not determinant, for firm innovation. In organisationally thinner RIS—as well as locations that are organisationally thick but little diversified—firms are surrounded by a relatively narrow variety of organisations that can stimulate different learning and innovation paths. However, firms in these regions can tap into collaboration with extra-regional organisations to obtain the knowledge they need to innovate. Thus, the disadvantages stemming from their location can be compensated for via extra-regional knowledge links.

This thesis compares factors that are positively associated with industry–university collaboration in non-metropolitan and metropolitan regions. I analyse regions through the lenses of the *organisational thickness and diversity* RIS classification developed by Trippl et al. (2015a) and Zukauskaite et al. (2017). Compared to other approaches, this RIS classification is better suited to comparing how firms learn and innovate in metropolitan and non-metropolitan regions. These areas are expected to differ in their degree of organisational thickness and diversity, and this difference relates to how firms learn and innovate. For instance, learning from organisations outside the home

region is expected to be more common among firms in non-metropolitan regions, compared to those in cities. In papers A and D in the present thesis, regions are also implicitly analysed through the lenses of the *knowledge base* RIS classification developed by Asheim and Coenen (2005) and Asheim et al. (2011). In non-metropolitan regions, the local RIS is expected to be closer to the synthetic knowledge base RIS because firms that *do not* traditionally rely on university research are relatively common in that area. Meanwhile, in metropolitan regions, the local RIS is expected to be closer to the analytic knowledge base RIS because firms that *do* rely on university research are relatively common in these areas (Tödtling and Trippl, 2015, 2005). Papers A and D focus on non-metropolitan regions, and the *knowledge base* RIS helps us consider that these areas are endowed with relatively more firms that do not traditionally rely on university research compared to their urban counterparts. Before proceeding to a more in-depth discussion on how external knowledge sourcing takes place in different types of regions, the next section will specify further the geographical classifications of regions used in this thesis.

1.2.2. GEOGRAPHICAL CLASSIFICATIONS OF REGIONS

The present study takes stock of the debates in the geography of innovation literature on the definition of regional peripheries. Although progress has been made in this area, a range of definitions is used, and there is a lack of consensus on what a regional periphery is. Definitions include: i) geographical aspects, such as transportation costs due to lower accessibility; ii) economic characteristics, such as lack of infrastructure supporting innovation processes, human capital, and the dominance of businesses from sectors not relying heavily on scientific research and R&D for innovation; and iii) demographic characteristics, such as low population density and population decline. Most geography of innovation researchers define regional peripheries as regions with cities and rural surroundings; others see peripheries as predominantly rural. These definitions are not inconsequential since peripheries with relatively large towns and relatively high population density are more likely to host infrastructure that supports innovation processes, like universities or public research organisations (Eder, 2019).

Indeed, sometimes peripheries are characterised as regions that are predominantly rural and where a university presence is mostly limited to branch campuses. These characterisations include economic aspects, such as an industry structure dominated by businesses with relatively low levels of spending in R&D, relatively low levels of human capital, and a very limited university presence, but also geographical aspects, such as the relative isolation of these regions from the main communication infrastructure and metropolitan areas. In addition, demographic aspects such as a low, declining population density are considered (Charles, 2016; Doloreux and Dionne, 2008; Isaksen and Trippl, 2017; Jauhiainen and Moilanen, 2012; Shearmur, 2015;

Shearmur and Bonnet, 2011; Shearmur and Doloreux, 2016; Tödtling and Trippl, 2015).

Other publications characterise peripheries as regions with, at minimum, a city with a main university campus and a rural hinterland. As such, their definition of periphery focuses mostly on economic factors, such as an industry structure characterised by businesses with relatively low levels of spending in R&D or relatively low levels of human capital. Compared to defining peripheries as predominantly rural regions, the regions included in these publications have less ground to be considered as geographical or demographic peripheries since they are not (extremely) isolated. Because they host at least one city, they are more densely populated than predominantly rural locations, and they do not experience acute problems of population decline either (Alpaydin et al., 2018; Evers, 2019; Fitjar and Rodríguez-Pose, 2011a; Nilsson, 2006; Rodrigues and Teles, 2017; Tödtling and Trippl, 2015).

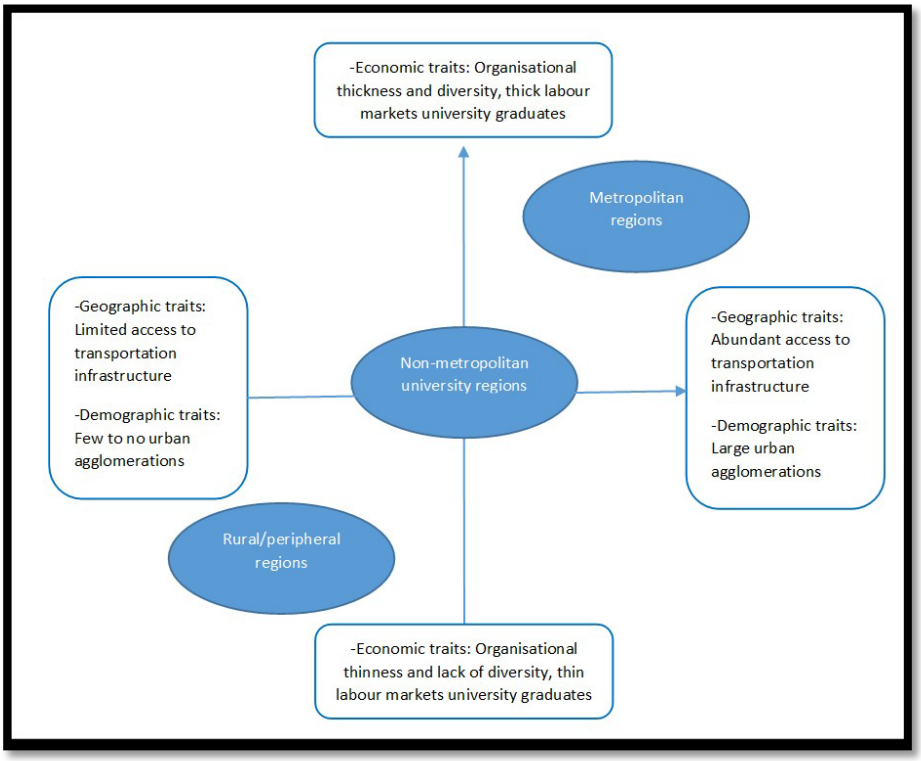
The present thesis considers both characterisations of regional peripheries, defining those regions that are not metropolitan as either (a) rural/peripheral regions or (b) of non-metropolitan university regions. The latter group is defined as more peripheral than metropolitan regions because of its economic characteristics; meanwhile, the former is defined as more peripheral than non-metropolitan university regions, and metropolitan regions because of its economic, geographical and demographic characteristics. Together with the category of metropolitan regions, these are the types of regions considered in the present thesis. Figure 1 summarises the traits of the three regions: non-metropolitan university regions, rural/peripheral regions, and metropolitan regions.

1.2.2.1 Non-metropolitan university regions

Non-metropolitan university regions differ from metropolitan regions in terms of their economic traits. The former are less organisationally thick and diverse than their metropolitan counterparts, thus, their economic infrastructure is less dense than that of large urban areas. While non-metropolitan university regions host universities (at least a main campus), they are home to a relatively narrow variety of firms in different industries, and some of these industries are unlikely to rely heavily on scientific research and R&D as part of their innovation processes (Isaksen and Karlsen, 2013; Tödtling and Trippl, 2015; 2005). As such, these regions correspond roughly to the organisationally thick and specialised regions used in the RIS literature (Isaksen and Trippl, 2017; Trippl et al., 2018, 2015a).

In addition, they host a smaller proportion of university graduates in their workforce compared to metropolitan regions, and relatively thin labour markets mean that graduates might experience challenges in finding a position that fits their skills. As a result, graduate out-migration to the thicker labour markets of metropolitan regions is common (Ahlin et al., 2014; Scott, 2010; Storper and Scott, 2009). The metropolitan regions studied in this thesis are, in addition, capital regions; as a result, they are likely to possess (even) thicker labour markets for university graduates, owing to the demand for graduate employment in governmental offices.

Figure 1: Types of regions considered in the thesis



Source: own elaboration.

It should also be noted, however, that in some non-metropolitan university regions, the local university has devoted considerable educational and research efforts to the development of industries oriented to university research (Boucher et al., 2003), such as ICT (Guerrero and Evers, 2018), renewable energies (Alpaydin et al., 2018), or materials technologies (Rodrigues and Teles, 2017). The efforts conducted by these

non-metropolitan universities also entail that the graduates they train tend to be relatively well-suited to the needs of the regional labour market, whether in emerging science-oriented industries or in the rest of the labour market. As a result, non-metropolitan university regions that are home to such academic institutions have been able to retain large proportions of their graduate workforce (Evers, 2019; Faggian and Mccann, 2009). Non-metropolitan university regions do not experience acute levels of geographical isolation since they are connected to major transportation infrastructure, such as railways, motorways, ports and airports, and demographically, they are home to at least a medium-sized city (Eder, 2019; Tödtling and Trippl, 2015).

1.2.2.2 Rural/peripheral regions

The category of rural/peripheral regions characterises regional peripheries as locations that differ from metropolitan regions in their economic, geographic and demographic traits. Differences in the same dimensions are also visible between rural/peripheral regions and non-metropolitan university regions. Economically, university presence in rural/peripheral regions is likely to be limited to branch campuses with limited research capacity (Boucher et al., 2003; Charles, 2016). Education levels are likely to be lower than those of the other two region types, with acute problems of graduate out-migration owing to thin labour markets where graduates are unlikely to find positions that fit their skills (Ahlin et al., 2014; Faggian and Mccann, 2009). There is a narrower variety of industries compared to non-metropolitan university regions, and local industries are less likely to rely on university research and R&D (Isaksen and Trippl, 2017; Tödtling and Trippl, 2015, 2005). They experience relatively high levels of geographical isolation since they do not host major transportation infrastructure, although they might be at commuting distance from, for instance, railways and motorways (Doloreux and Dionne, 2008; Shearmur and Bonnet, 2011). Demographically, population density is lower than that of non-metropolitan university regions, and these areas are likely to suffer de-population issues (Eder, 2019; Jauhiainen and Moilanen, 2012). Roughly, they correspond in the RIS literature to organisationally thin regions (Isaksen and Trippl, 2017; Trippl et al., 2018; 2015a).

In some instances, rural/peripheral regions might be at commuting distance from a metropolitan area and may not suffer from particularly acute geographical isolation (Doloreux and Dionne, 2008; Shearmur and Bonnet, 2011). However, despite these exceptions, rural/peripheral regions are more likely to be seen as geographic and demographic peripheries than are non-metropolitan university regions (Jakobsen and Lorentzen, 2015; Shearmur, 2015; Shearmur and Doloreux, 2016).

1.2.2.3 Metropolitan regions

Metropolitan regions are defined as relatively central in their economic, demographic and geographic dimensions. Demographically, they contain metropolitan areas, as well as a densely populated hinterland. Economically, they are organisationally thick and diverse, hosting multiple universities and public research institutions; as well as a relatively broad range of industries, including high technology, science-based businesses (McCann, 2008). Complementary to that, they contain thick labour markets, where university graduates can find a relatively easy match between their skills and the demand for labour.[2] As a result, these regions attract increasing populations of graduates (Ahlin et al., 2014; Faggian and Mccann, 2009; Scott, 2010; Storper and Scott, 2009). Geographically, they are connected to the main transportation infrastructure, as they are key nodes in the global knowledge pipelines (Bathelt et al., 2004; Rodríguez-Pose and Fitjar, 2013). They are roughly equivalent to the organisationally thick and diversified regions of the RIS literature (Isaksen and Trippl, 2017; Trippl et al., 2018; 2015a).

In each paper below, different geographical classifications are applied. Paper A analyses industry–university collaboration patterns in a non-metropolitan university region, North Denmark, because the goal of this paper is to understand how the educational and research activities of the region's university have co-evolved with local, emerging industries. Papers B and C focus on comparing patterns of industry–university collaboration among firms in all three types of regions. Paper D analyses industry–university collaboration patterns primarily in non-metropolitan university regions, but cases from metropolitan regions are also included to highlight factors associated with the start and unfolding of industry–university collaboration in non-metropolitan university regions. Section 1.5, which discusses the content of the papers, explains in more detail how the papers differ in the geographical classifications of regions they describe. Having defined the classifications used in this thesis, I turn to a discussion of how firms' external knowledge sourcing takes place in different types of regions.

1.2.3. EXTERNAL KNOWLEDGE SOURCING, AND ITS INTERPLAY WITH REGIONAL LOCATION

It has long been recognised by scholars of organisational learning that firms' innovativeness depends on their knowledge base (Kogut and Zander, 1992); likewise, it is necessary for firms to expand their knowledge base by engaging in knowledge

[2] If this match is not readily available, metropolitan regions' thick labour market allows for relatively easy job switching, until graduates find a position suited to their skills (Ahlin et al., 2014).

exploration if they are to maintain and increase their capacity to innovate (March, 1991). Firms that combine internal and external knowledge are better able to innovate than those that do not because combining new knowledge with information they already possess enables them to realise solutions (e.g. product and service developments, production processes, organisational change) that are otherwise unavailable (Rosenkopf and Nerkar, 2001). However, the ability of firms to make use of external knowledge is intimately linked to their ability to acquire, interpret and assimilate it in their knowledge base, that is their absorptive capacity (Cohen and Levinthal, 1990; 1989; Zahra and George, 2002). Indeed, higher levels of absorptive capacity enable firms to engage more readily in knowledge exploration and to benefit from integrating new knowledge into the firm's base (Rothaermel and Alexandre, 2009).

External knowledge sourcing seems, up to a point, to be positively associated with innovation, with an inverse u-shaped relationship between the number of source types that firms draw knowledge from and the likelihood of innovation (Laursen and Salter, 2006). However, there is conflicting evidence on the extent to which firm innovativeness benefits from combining knowledge from sources that are cognitively proximate, such as customers and suppliers, with sources that are not, such as universities (Criscuolo et al., 2018; Haus-Reve et al., 2019). In any case, there are positive associations between: sourcing knowledge from consultants and firms' innovativeness (Tether and Tajar, 2008); sourcing knowledge from research and technology organisations and firms' introduction of new-to-market innovations (Giannopoulou et al., 2019); and firms' collaboration with universities and their introduction of new-to-market innovations (Hewitt-Dundas et al., 2019).

In section 1.2.1, it was formulated that firms in organisationally thin regions might resort to extra-regional collaboration channels to source knowledge to a greater extent than do firms in organisationally thick, diversified regions. Among firms in non-metropolitan university regions and, in particular, rural/peripheral regions, extra-regional collaboration channels can provide knowledge that is useful for innovation, rather than informal, face-to-face meetings with staff from other nearby organisations (Fitjar and Rodríguez-Pose, 2013; Storper and Venables, 2004). For firms in relatively isolated locations, identifying useful knowledge sources, and establishing and maintaining formal collaboration channels with them, requires more organisational commitment than informal interactions based on geographical proximity. Thus, the firms involved in the maintenance of these collaboration channels tend to have higher absorptive capacity than those that are not. Evidence supporting this argument has been found in Sweden (Grillitsch and Nilsson, 2015), Canada (Shearmur and Doloreux, 2018, 2016) and Norway (Jakobsen and Lorentzen, 2015).

Thus, the association between external knowledge sourcing and innovation appears to vary depending on the type of region where firms are located. The literature cited in the present section suggests that, compared to firms in metropolitan areas, formal

collaboration channels appear to be more relevant to innovation among firms in non-metropolitan university and rural/peripheral regions because these collaboration channels compensate for the relative scarcity of knowledge sources in the latter regions. Section 1.2.4 explores the factors associated with one form of external knowledge sourcing, industry–university collaboration.

1.2.4. FACTORS ASSOCIATED WITH INDUSTRY-UNIVERSITY COLLABORATION

Firms and universities can interact through multiple channels. Perkmann and Walsh (2007) classify those channels according to their degree of relational involvement; the categories range from links with little or no relational involvement, like the commercialisation of intellectual property, to links with high degrees of relational involvement, like research services—contract research, consultancy services provided by university researchers to private clients—and research partnerships, where both parties commit R&D resources. In between, some links, such as student internships in industry and the promotion of academic entrepreneurship, require a moderate degree of relational involvement.

The papers in this thesis define industry–university collaboration as activities where the parties involved cooperate with the goal of developing innovations.[3] This definition includes industry–university links that require a high degree of relational involvement, using Perkmann and Walsh's (2007) classification, but excludes research contracts and consultancy services. This definition is akin to that of the Community Innovation Surveys (CIS) carried out by the EU member states and some of the ESS member states (Eurostat, n.d.).[4]

The precise definition of collaboration, however, varies with the thesis paper. Paper A does not deal explicitly with collaboration; therefore, no precise definition is specified. Papers B and C use a definition of collaboration similar to that of the CIS; paper D defines collaboration as an activity where both parties not only cooperate, but also commit R&D resources to develop innovations. Using Perkmann and Walsh's (2007) classification, the definition of industry–university collaboration applied in

[3] Following the formulation developed in the CIS (Eurostat, n.d.), the following definitions of innovation are included: the introduction in the market of new goods or services; new production processes, distribution methods or supporting activities; new organisational methods; and new marketing techniques.

[4] In the CIS surveys, collaboration on innovation is defined as a relationship where the parties actively cooperate on innovation activities. Pure contracting-out of work is excluded from such definition.

paper D is restricted to research partnerships, whereas the definition of industry–university collaboration used in papers B and C includes collaborations that do not fall under the category of research partnerships because the parties do not necessarily have to commit R&D resources.

Firms can collaborate on innovation with a broad range of organisations, and the evidence shows that they are much more likely to work with other types of organisations than with universities. A larger percentage of firms collaborates with organisations typical of the value chain (that is, suppliers and customers) than universities (Fitjar and Rodríguez-Pose, 2011b; Hewitt-Dundas et al., 2019; Jakobsen and Lorentzen, 2015). Moreover, although previous research has shown that firms connected to universities are more likely to innovate (Hewitt-Dundas et al., 2019), industry–university collaboration can also be a challenging path to innovation. This is because universities are governed by different norms and incentive systems than those of firms, and firms might have to do adapt to universities' norms and incentive systems (Bruneel et al., 2010). Firms with little financial slack might find industry–university collaboration more challenging than firms with abundant financial resources (Bruneel et al., 2016). Firms in sectors that draw heavily on scientific research are more likely to tap into university knowledge for innovation compared to those less engaged in scientific research (Laursen and Salter, 2004; Pavitt, 1984; Segarra-Blasco and Arauzo-Carod, 2008).

Thus, industry–university collaboration is far from a common practice among firms, and the evidence points to a series of factors that are positively associated with it. Among these are larger size and higher absorptive capacity, whether measured as spending in R&D over sales (Laursen and Salter, 2004; Segarra-Blasco and Arauzo-Carod, 2008), or as the proportion of university graduates in the firm workforce (Drejer and Østergaard, 2017; Laursen et al., 2011). This positive correlation exists because it is easier for firms to commit resources to relations with universities. However, graduates not only contribute to their firms' absorptive capacity but also provide links to the university where they obtained their degree. Graduate employees can, for instance, provide their employers with closer knowledge of the research conducted at universities, and of how to approach academic researchers from the universities where they obtained their degree (Drejer and Østergaard, 2017).

Collaboration with higher education institutions is also more likely for businesses that benefit from government support schemes because these schemes create a financial incentive to develop such links (Mohnen and Hoareau, 2003; Segarra-Blasco and Arauzo-Carod, 2008). The same goes for firms that are geographically proximate to universities because geographical proximity to universities enables the transmission of complex, tacit knowledge through face-to-face meetings (Audretsch and Feldman, 1996; D'Este et al., 2013; D'Este and Iammarino, 2010; Feldman and Florida, 1994; Jaffe et al., 1993).

Finally, sourcing knowledge from locations other than universities is also positively associated with industry–university collaboration (Laursen and Salter, 2004). Firms that have worked with certain types of organisations (customers, among businesses with less than 50 employees; consultants, among larger businesses) are more likely to collaborate with universities because they have already learned to cooperate with other organisations, despite differences in norms and working practices (Hewitt-Dundas et al., 2019).

Thus, many factors are positively associated with industry–university collaboration; however, it is still unclear how these factors operate in specific regional settings. Sections 1.2.5 and 1.2.6 discuss this knowledge gap by conceptualising models of university involvement in industry–university collaboration at the regional level and formulating the research sub-questions.

1.2.5. CONCEPTUALISATIONS OF UNIVERSITIES' THIRD MISSION

Since the 1980s, policymakers have intensified their call for universities' involvement in the development of third mission activities, that is activities aimed at applying university knowledge in society. In a context of economic slowdown and diminishing public budgets for university research, policies have increased universities' incentives to establish links with regional firms, providing in turn an alternative funding source. Legal changes such as the Bayh-Dole in the US promoted the transition to a university oriented to collaborative research with firms (Uyarra, 2010). Since then, different models have aimed at capturing the ways in which universities have implemented such third mission activities (Uyarra, 2010).

In the *entrepreneurial university model*, fulfilling the third mission has involved an increased emphasis on research commercialisation services and the development of spin-offs, and universities have adapted a range of activities, such as educational degree provision, consultancy services, contract research, and research collaboration, to support innovation in regional firms (Clark, 2004, 1998; Gjerding et al., 2006; Uyarra, 2010). The *engaged university model* goes one step further by promoting the inclusion of third-mission activities in "*all the key functions: promoting social inclusion and mobility, providing a base for skill development, and stimulating innovation through basic scientific research*" (Uyarra, 2010, pp. 1238–1239). In this model, regional needs—economic or not—become integrated in university strategies and in their educational and research missions. Universities also become involved in the leadership of regional networks for social, cultural and economic development, and for offering policy advice (Breznitz and Feldman, 2012; Trippl et al., 2015b; Uyarra, 2010). Another model that goes beyond the paradigm of the entrepreneurial university model is that of *mode 2*; within this model, universities have focused their research around societal challenges (Trippl et al., 2015b).

In these models, restricted access to public funding has incentivised firms to search for funding streams outside the block grants allocated by education ministries. In the entrepreneurial university model, access to private-sector resources is hypothesised to stimulate universities' education and research links with industry (Clark, 2004; 1998; Gjerding et al., 2006); although the relatively limited revenues generated by technology transfer offices cast doubt about their effectiveness, as a third mission activity that can gather private funding (Uyarra, 2010). In the engaged university model, national programmes and EU structural funds have incentivised the involvement of universities in defining regional development priorities. Public funding streams, such as those of the EU framework programmes, have oriented universities to focus their research around societal challenges, as in the mode 2 model (Trippl et al., 2015b; Uyarra, 2010).

Although the universities studied in this thesis (Aalborg University, the University of Aveiro, the University of Stavanger[5]) have developed activities that correspond to the three university models to different degrees, in the remainder of the thesis, universities' activities are examined through the lens of the entrepreneurial university model. This model takes into account that universities have adapted their educational and research missions to support innovation in regional firms and have developed third-mission activities, such as the establishment of science parks, aimed at supporting the development of spin-offs. The entrepreneurial university model thus covers different types of industry–university links, including those that have been defined as research partnerships (Perkmann and Walsh, 2007). The industry–university links included in this model are also suited to the study, in paper A, of how universities' educational, research and third-mission activities co-evolve with industrial developments at the level of their region (see section 1.5 for more details about the paper).

Other university models provide lenses that are less suitable for the purposes of the present thesis. The mode 2 model does not pay enough attention to industry–university collaborations that do not respond to societal challenges; likewise, the focus of the engaged university model on policy advice and regional network leadership goes beyond the scope of the present thesis. However, the choice of the entrepreneurial university model comes with limitations. The involvement of a university in regional networks and in policy advice might stimulate, in the long run, the establishment and development of industry–university collaborations, activity that might be overlooked when thinking only in terms of the entrepreneurial university model. The inability to capture these *indirect* relationships might be a potential limitation, especially in papers A and D, where the use of qualitative research methods allows us to study the

[5] Aalborg University is located in the region of North Denmark; the University of Aveiro in the Aveiro region (Portugal); and the University of Stavanger in the Rogaland region (Norway).

development of industry–university collaboration in depth (see section 1.4 for a more detailed discussion of the research methods applied in the thesis papers).

1.2.6. INDUSTRY-UNIVERSITY COLLABORATION, IN DIFFERENT TYPES OF REGIONS

Through activities such as the training of university graduates to meet the needs of public and private employers, entrepreneurship support or research collaborations with businesses, universities have supported innovation and development in their regions (Boucher et al., 2003; Charles, 2006; Drucker and Goldstein, 2007). Universities in non-metropolitan university regions often commit a large share of their educational activity to training graduates to meet the needs of the regional labour market,[6] as in the entrepreneurial university model. These activities have helped improve the fit between graduate education and regional economic needs, increasing graduate retention in these regions (Boucher et al., 2003; Evers, 2019; Faggian and Mccann, 2009; Nilsson, 2006). These universities can also be seen as entrepreneurial universities because they have oriented their research efforts to support regional firms. Through activities such as contract research, research collaborations and the establishment of research centres or science parks, these efforts have supported innovation in the industries of their home regions. The same research activities have also contributed to transforming the local industrial landscape, supporting the transformation of existing industries or the creation of new ones (Isaksen and Trippl, 2017; Nilsson, 2006; Pedersen, 2005; Rodrigues and Teles, 2017).

A deeper look at the activities of non-metropolitan universities might help us explore how these institutions contribute to industry–university collaboration in their home regions. Hence, the first research sub-question contributes to the main research question by exploring the following:

RSQ1) How do the actions of non-metropolitan universities contribute to industry–university collaboration on innovation in non-metropolitan university regions?

Graduate employees increase firms' absorptive capacity (Laursen and Salter, 2004). They can also provide their firms with closer knowledge of the research conducted at universities and of how to approach academics at those schools (Drejer and Østergaard, 2017). At the same time, non-metropolitan university regions and rural/peripheral regions are likely to be less attractive to university-trained professionals than their metropolitan counterparts because of the relative absence of

[6] This is particularly the case of relatively young, post-war institutions established with the goal of providing access to higher education in regions where access to these opportunities was hitherto very limited (Boucher et al., 2003; Evers, 2019; Faggian and Mccann, 2009).

thick labour markets that are so attractive to university graduates (Ahlin et al., 2014; Faggian and Mccann, 2009; Scott, 2010; Storper and Scott, 2009). The extent to which both non-metropolitan university regions and rural/peripheral regions are well-endowed with graduate employees compared to metropolitan regions, might have consequences for the roles played by university graduates employed at firms; specifically, the presence of more alumni employees may be associated with more extensive industry–university collaboration. Hence, the second research sub-question explores how the employment of university graduates by firms is associated with firms' collaboration on innovation with universities across the three regions explored here.

RSQ2) To what extent does the association between graduate employment and industry–university collaboration on innovation differ across types of regions?

Whether firms gather knowledge from sources other than universities is another factor that is positively associated with industry–university collaboration (Hewitt-Dundas et al., 2019; Laursen and Salter, 2004). In turn, the relationship between firms' sourcing of external knowledge and their collaboration with universities might also vary with the type of region where firms are located. Compared to metropolitan regions, firms in rural/peripheral or non-metropolitan university regions are more likely to rely on collaboration channels with organisations outside their home region in order to source knowledge not available locally (Grillitsch and Nilsson, 2015; Jakobsen and Lorentzen, 2015; Shearmur and Doloreux, 2016). Conversely, firms in metropolitan regions are more likely to rely on informal, face-to-face interactions to source knowledge due to their organisational thickness and diversity (Rodríguez-Pose and Fitjar, 2013; Storper and Venables, 2004). The third research sub-question contributes thus to the main research question by exploring inter-regional variations in the association between firms' external knowledge sourcing strategies, and their collaboration with universities.

RSQ3) To what extent does the association between external knowledge sourcing strategy and industry–university collaboration on innovation differ across types of regions?

1.2.7. OVERVIEW OF THE THESIS PAPERS, RELATIONSHIP WITH THE RESEARCH SUB-QUESTIONS

This section discusses how the papers relate to each other and answer the research sub-questions. First, the goals and research method of each paper are introduced and connected to the research sub-questions they intend to answer. Next, the section delineates how the papers relate to each other, in connection to the research sub-questions.

Paper A (Guerrero and Evers, 2018) explores under what conditions the educational, research and third-mission efforts of a young, non-metropolitan university can contribute to the development of new industries reliant on university research in its home region. A case study approach is followed, comparing how Aalborg University's research activities and efforts in training graduates suited to the regional labour market have influenced the development of localised capabilities (Maskell et al., 1998) supporting the development of the ICT and biomedical industries in North Denmark. This case study answers RSQ1 by providing insights on the role that a non-metropolitan university can play as a driver of industry–university collaboration for innovation in its home, non-metropolitan university region through educational, research and third-mission activities.

Paper B (Guerrero, 2020a) uses quantitative methods—logistic regression analyses—to analyse the extent to which employing university graduates is positively associated with firms' collaboration with universities on innovation across the three types of regions in Denmark, helping to answer RSQ2. The paper also compares the extent to which external knowledge sourcing strategy is positively associated with collaboration between universities and firms, across region types, addressing RSQ3. In the paper, rural/peripheral regions are labelled as rural regions, and non-metropolitan university regions as intermediate regions.

Paper C (Guerrero, 2020b) examines the extent to which collaborating with RTOs is positively associated with firms' collaboration with universities for innovation, across the three region types in Denmark. Using quantitative methods—logistic regression analyses—, this paper helps to answer RSQ3. In the paper, rural/peripheral regions are labelled as peripheral regions.

Finally, paper D (Guerrero, 2020c) explores, through multiple case studies, the association between factors related with SME–university collaboration and the start and unfolding of collaboration for innovation in non-metropolitan university regions. To highlight these associations, paper D also includes comparable case studies in metropolitan regions. The paper contributes to answering the research sub-questions by exploring the role played in the development of industry–university partnerships by: the educational, research and third-mission activities of non-metropolitan universities (RSQ1); the connections that graduate employees provide to university researchers (RSQ2); and firms' external knowledge-sourcing strategy (RSQ3). In addition, the association between these factors and industry–university collaboration is explored with a degree of detail not available in the rest of the papers through multiple, firm-level case studies. This means that it is possible to explore how these factors are associated with the establishment of firm–university linkages, as well as the transformation of industry–university linkages into full-fledged collaborations. Table 1 summarises the contributions of each paper to help assesses how the papers relate to each other, in connection with the research sub-questions and the main research question.

Table 1: Contribution of the papers to the research questions					
		Paper A	**Paper B**	**Paper C**	**Paper D**
RQ: *To what extent do the roles of key factors associated with industry-university collaboration differ across types of regions?*	RSQ1: *How do the actions of non-metropolitan universities contribute to industry–university collaboration on innovation in non-metropolitan university regions?*	-How can a non-metropolitan university contribute, through its educational, research and third-mission activities, to the development of new industries in its home region?			-Role of educational, research and third-mission activities of universities, in start and unfolding of links between universities and SMEs, in non-metropolitan university regions
	RSQ2: *To what extent does the association between graduate employment and industry–university collaboration on innovation differ across types of regions?*		-Assesses to what extent graduate employment is positively associated with industry–university collaboration, across types of regions in Denmark		-Role of graduate employment, in start and unfolding of collaborations between universities and SMEs, in non-metropolitan university regions
	RSQ3: *To what extent does the association between external knowledge-sourcing strategy and industry–university collaboration on innovation differ across types of regions?*		- Assesses to what extent external knowledge-sourcing is positively associated with industry–university collaboration, across types of regions in Denmark	-Assesses to what extent collaboration with RTOs is positively associated with industry–university collaboration, across types of regions in Denmark	-Role of external knowledge-sourcing, in start and unfolding of collaborations between universities and SMEs, in non-metropolitan university regions

1.3. EMPIRICAL SETTINGS

This section is divided into two parts. First, the national contexts of the regions where the research has been conducted are described. Second, a discussion of the regions and universities where the research has been conducted is provided.

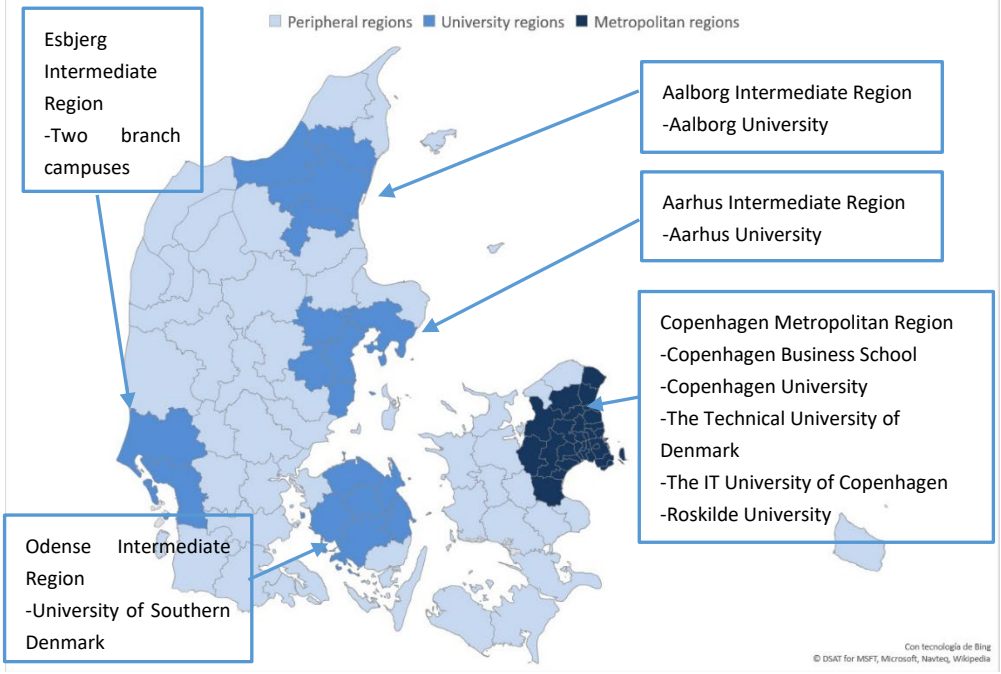
1.3.1. NATIONAL CONTEXTS

Thesis papers A–C are based on data from Denmark. This Scandinavian country in the northern tip of continental Europe provides an interesting research setting for scholars interested in the geography of innovation and in industry–university collaboration. Its size—42.925 km^2—is almost 4 times smaller than the EU-28 average (Eurostat, n.d.). Geographical distances are, thus, shorter than many European countries, and firms are typically within a few hours' car ride from potential university partners. However, as suggested in figure 2, population densities in a relatively small country like Denmark are far from even.

Figure 2 displays the distribution of rural/peripheral, non-metropolitan university and metropolitan regions of Denmark, as defined in the present thesis. Using the OECD (n.d.) list of functional urban areas, those with a population of 50,000–500,000 are defined as non-metropolitan university regions, and those with over 500,000 inhabitants are considered metropolitan regions. The distribution of the three region types across Denmark is, thus, not based on administrative borders. More details on the method used to define the types of regions are provided in papers B and C.

Using demographic data from Statistics Denmark (n.d.), it is possible to highlight the differences in population size and density between each type of region; of 5,748,769 inhabitants in 2017, roughly one-third of them—1,941,850—lived in the metropolitan region of Copenhagen. This figure contrasts with those of the non-metropolitan university regions, whose populations range from 508,352 (Aarhus) to 169,702 (Esbjerg); moreover, Aarhus is defined as a non-metropolitan university region because it only reached the 500,000-inhabitants mark in 2016, and the datasets used in papers B and C could only cover until 2015. In total, the non-metropolitan university regions were home to 1,372,782 inhabitants. The rest of the population—roughly 2.4 million inhabitants—lived in the rural/peripheral regions. In 2017, the population density of the Copenhagen metropolitan region—817 inhabitants per km^2—was much higher than the average of the non-metropolitan university regions—136 inhabitants per km^2—and the rural/peripheral regions—80 inhabitants per km^2.

Figure 2: Rural/peripheral, non-metropolitan university and metropolitan regions



Source: Based on Guerrero, 2020b; Danish Ministry of Higher Education and Science, n.d.; Nielsen et al., 2018; OECD, n.d.; Statistics Denmark, n.d.

As shown in table 2, differences among region types are remarkable when it comes to the number of universities. Only about one-third of Danish universities—Aalborg University, Aarhus University and the University of Southern Denmark—have their main campus located outside the Copenhagen metropolitan region. Beyond that, university presence is a relatively recent phenomenon outside the Copenhagen metropolitan region; before the second half of the 20th century all Danish universities except for Aarhus were located in the Copenhagen metropolitan region.

Aalborg University and the University of Southern Denmark were founded after regional actors exerted considerable pressure for the establishment of higher education institutions in their home regions (Gregersen et al., 2009; Nilsson, 2006). Their founding provided access to university education to regions who otherwise had few opportunities to access this type of degrees (Evers, 2019). These institutions have come to be regarded as key players in the innovation systems of their regions, developing educational, research and third-mission activities suited to the needs of the regional labour market and promoting innovation among regional firms (Gregersen et al., 2009). In Denmark, non-metropolitan universities—particularly Aalborg University and the University of Southern Denmark—have thus been intensively

involved in the development of their regions. For Aalborg University, this involvement started early with the provision of degrees suited to the needs of the emerging ICT industry, and the development of collaborative research projects supporting research and product development needs in this industry (Guerrero and Evers, 2018).

Table 2: Characteristics of Danish universities	**1. Region type**	**2. Year established**	**3. Overall score times higher education**	**4. Student population (2017)**
Aalborg univ.	Non-metro. univ.	1974	46.3-50.4	20,825
Aarhus univ.	Non-metro. univ.	1928	60.3	33,120
Univ. of Southern Denmark	Non-metro. univ.	1966	43.5-46.2	22,644
Univ. of Copenhagen	Metro.	1479	58.2	38,481
Copenhagen Business School	Metro.	1917	43.5-46.2	14,911
Technical univ. of Denmark	Metro.	1829	52.5	11,221
Roskilde univ.	Metro.	1972	27.6-32.5	8,516
IT univ. of Denmark	Metro.	1999	n/a	1,811

Sources: Drejer and Østergaard, 2017, p. 1196; Times Higher Education, 2017; Danske Universiteter (n.d.).

Despite the development of non-metropolitan universities, main university campuses can only be found, at the practice, in non-metropolitan university regions of at least 300,000 people; the smallest of these regions that is home to a non-metropolitan university is that of Aalborg and its surrounding municipalities, with 316,037 inhabitants in 2017. Close to half of the Danish population—more than 2.4 million people in the rural/peripheral municipalities and in the Esbjerg region—lives in regions that are only home to branch campuses. Regional differences are also visible when it comes to the percentage of the population between the ages of 25 and 64 that

held a university degree in 2017: 6.73% did so in the rural/peripheral regions, well below the 14.90% of the non-metropolitan university regions and the 24.94% of the Copenhagen metropolitan region (Statistics Denmark, n.d.).

Hence, the Danish context presents interesting traits related to industry–university collaboration, as discussed in the literature review. On one hand, the relatively short geographical distances separating firms from universities in Denmark suggest that geographical distance should pose a smaller obstacle to industry–university collaboration, compared to larger countries. On the other hand, regional imbalances in the presence of universities suggest that geographical proximity is less likely to facilitate industry–university collaboration in the rural/peripheral regions, compared to the non-metropolitan university regions, and in particular the Copenhagen metropolitan region. Another concern involves whether (and how) regional differences in the population of university graduates are relevant to the development of industry–university collaboration. However, since their early years, non-metropolitan universities in Denmark have developed a range of educational, research and third-mission activities suited to the innovation needs of their regions; this could provide firms in non-metropolitan regions—in particular, non-metropolitan university regions—a setting as favourable to industry–university collaboration as that of the Copenhagen metropolitan region.

Finally, Denmark also provided an interesting research setting for the thesis because of the availability of register data. Combined with the Danish Research and Innovation data, the data from the IDA database allows to compare, across region types, how different factors are statistically associated with industry–university collaboration. Through the IDA database, it is possible to determine the postcode of the firms that participated in the Danish Research and Innovation survey; firms can, thus, be classified by region type, depending on their postcode or municipality. Furthermore, it is possible to assign firms, through their postcode or municipality, to different categories of economic regions. This frees us from classifying firms according to administrative regions with little linkage to economic realities. Unfortunately, the ability to combine register and innovation survey data was restricted to Denmark for the purposes of the present thesis; hence, cross-country comparative analyses are only presented in paper D, which uses a multiple-case-study approach (see below).

Paper D is a comparative case study that examines factors behind the start, and unfolding of collaboration between SMEs and universities in non-metropolitan university regions of Denmark, Norway and Portugal. In metropolitan regions of the same countries similar factors are also explored in order to highlight what is characteristic about SME–university partnerships in non-metropolitan university regions. A comparison with geographic and education statistics of Norway and Portugal highlights traits specific to Denmark while providing context data on the other two countries.

Table 3 points to Denmark as the smallest and most densely populated of the three countries; it also demonstrates the considerably larger size—and population sparseness—of Norway. Thus, geographical proximity is, in principle, less likely to facilitate industry–university collaboration in Norway than in Denmark and Portugal. Interestingly, however, collaboration with universities appears to be more common in Norway, even after taking into account differences in the percentage of firms that carry out innovative activities. Previous research has pointed out that firms in Norway tap into collaborations with extra-regional and international partners in order to innovate (Fitjar and Rodríguez-Pose, 2011b; Jakobsen and Lorentzen, 2015). Another national difference concerns the number of new doctorate holders per 1,000 inhabitants between 25 and 34 years old. Portugal is the country with the lowest attainment levels at this level of university education; the indicator points, thus, to lower levels of university-trained human capital in Portugal, compared to Denmark and Norway.

Table 3: Country characteristics	**Denmark**	**Norway**	**Portugal**
1. Population, 2017	5,748,769	5,258,317	10,309,573
2. Size (km^2)	42,925	323,381	92,227
3. Population density, 2017. Inhabitants/km^2	133.9	16.3	111.8
4. Percentage of firms that reported developing innovations, compared to overall firm population, 2014–2016 (2016–2018 for Norway)	44,1%	61%	66,8%
5. Percentage of innovative firms that reported collaborating with universities, 2014–2016	11%	20%	8,5%
6. New doctorates per 1,000 population aged 25–34, average 2010–2017	2.8	2.1	1.9

Sources: Rows 1–3: Eurostat (n.d.). Rows 4, 5: Direção-Geral de Estatísticas da Educação e Ciência (n.d.), Erhvervsstyrelsen (n.d.), Statistics Norway (n.d.). Row 6: European Commission (n.d.).

As discussed in more detail in paper D (Guerrero, 2020c), Denmark and Norway display a similar range of policies to stimulate firms' and universities' collaboration, including:

- Sector-based and cross-sectoral innovation networks in Denmark (Knudsen et al., 2018); cluster development schemes in Norway (Solberg, 2016).
- Schemes promoting firms' absorptive capacity and linkages with research organisations. In Denmark, the Innobooster scheme helps SMEs hire university graduates; meanwhile, innovation vouchers help SMEs purchase researcher services from universities (Knudsen et al., 2018). In Norway, the Norwegian Research Council supports R&D-based innovation activities, and Innovation Norway focuses on non-R&D innovation (Solberg, 2016).
- Industrial PhD and postdoc programmes, with Denmark introducing industrial PhDs in 1970. Norway followed in 2008, with an industrial PhD programme taking inspiration from Denmark (Grimpe, 2015; Solberg, 2016).

Paper D (Guerrero, 2020c) also discusses in more detail the range of policies implemented in Portugal to promote industry–university links, including collaborative R&D networks encompassing projects promoted by employers' associations and implemented by universities and cluster initiatives or tax incentives supporting R&D development. However, in contrast with its Scandinavian counterparts, low levels of absorptive capacity in the industrial fabric and the effects of the economic crisis that lasted most of the last decade have hampered the establishment and maintenance of industry–university links in Portugal. The economic crisis led to budget cuts in R&D spending, in particular in the private sector (Corado Simões et al., 2018; Mira Godinho and Corado Simões, 2015).

1.3.2. REGIONAL SETTINGS OF THE CASE STUDIES

Figure 3 displays the non-metropolitan university regions and the metropolitan regions where the case studies in paper D are conducted. The non-metropolitan university regions are North Denmark, Aveiro (Portugal) and Rogaland (Norway). The metropolitan regions—chosen to highlight traits of industry–university collaboration processes specific to the non-metropolitan university regions—are those of Copenhagen (Denmark), Lisbon (Portugal) and Oslo (Norway). These regions are also home to the countries' political capitals.

The non-metropolitan university regions have been chosen as case studies because they are home to young higher-education institutions with track records of supporting firms' innovation in their home regions, along the lines of the entrepreneurial

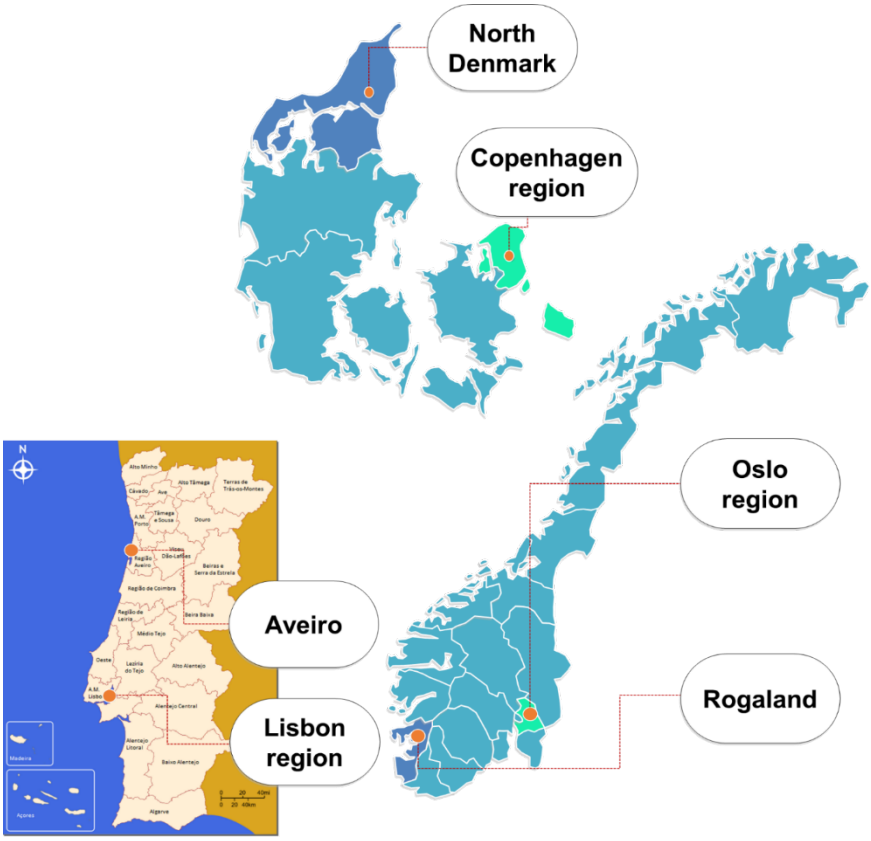
university model (Gjerding et al., 2006; Uyarra, 2010).[7] Thus, it was expected that it would be easier to find cases of firms involved in collaboration with these universities, compared to universities with more limited involvement in business support initiatives. The University of Aveiro was founded in 1973, Aalborg University in 1974 and the University of Stavanger in 2005. As discussed in more detail in paper D (Guerrero, 2020c), through educational, training and third-mission activities, the non-metropolitan universities chosen for the case studies have stimulated the renewal of the regional industrial fabric with the development of sectors related with scientific research, such as ICT in North Denmark, ceramics and building materials in Aveiro, or oil and gas in Rogaland. Beyond specific sectors, the three universities have committed considerable resources to educational, research and third-mission activities that can support innovation in regional firms, and that can be readily accessible to SMEs from sectors not traditionally reliant on university research. These include student projects conducted in collaboration with companies, where students work on problems posed by the firms, or the development of intermediaries aimed at helping SMEs access consultancy services (Alpaydin et al., 2018; Fonseca and Çinar, 2017; Guerrero and Evers, 2018; Rodrigues and Teles, 2017).

The non-metropolitan university regions have also been chosen because the local universities provided unparalleled access to case study data. Thanks to my involvement in the RUNIN project, managers from the non-metropolitan universities—which participate in the RUNIN project—helped me approach managers of partner firms and local university researchers involved in collaboration with the partner firms.

Table 4 shows that the regions where the case studies are conducted differ in population size and density. Typically, the metropolitan regions are 4–10 times more densely populated than their non-metropolitan counterparts, with the starkest difference occurring between the Copenhagen metropolitan region and North Denmark. These differences are coherent with the characterisation, described in section 1.2.2, of non-metropolitan university regions as less densely populated and organisationally thinner locations than metropolitan areas.

[7] The non-metropolitan universities in the case study also participate in international networks aimed at promoting universities' involvement in innovation and regional development, like the ECIU (https://www.eciu.org/).

Figure 3: Regions where paper D case studies are conducted



Sources: Author's elaboration using maps from Chocofrito (n.d).; Your Free Templates (n.d.).

Also in line with the categories described in section 1.2.2 is the fact that the non-metropolitan university regions where the case studies are conducted have a more limited presence of university students—measured as the percentage of students out of the overall population—and graduate employees—measured as the percentage of the population aged 25–64 with a university degree. Note, however, that the metropolitan regions are, as political capitals, home to multiple governmental organisations, and the need of these organisations for university-trained employees might explain, in part, why a larger percentage of a metropolitan region's population holds a university degree.

Table 4: Regional characteristics	**Norway**		**Denmark**		**Portugal**	
	Oslo metro.	**Rogaland**	**Copenhagen metro.**	**North Denmark**	**Lisbon metro.**	**Aveiro**
1. Population, 2017	1,271,127	472,024	1,807,404	587,335	2,821,349	363,752
2. Population density, 2017. Inhabitants/km^2	252.5	53.5	745.4	76.2	1,006.2	221.5
3. Number of universities	3	1	5	1	5	1
4. Students enrolled at local universities, latest data available	56,070	12,000	74,940	20,825	111,294	13,000
5. Students enrolled at local universities, as a percentage of the population	4.4%	2.5%	4.4%	3.4%	3.9%	3.6%
6. Percentage of firms that reported collaborating with universities,2014–2016 (all Norway; 2012–2014 for Denmark)	20%		16.5%	20.4%	10.3%	10.3%
7. Percentage of the 25–64 age-group that holds a university degree, average 2007–2017 (25–66 age group for Norway; 2011–2017 for Portugal)	16.7%	10.1%	20.4%	7.7%	29.2%	19.3%
8. Employment in medium and high-technology manufacturing, and in knowledge-intensive services as a percentage of the workforce. Index from the Regional Innovation Scoreboard 2017, compared to EU average 2011 (EU average 2011=100)	144.7	100.9	158.4	80.8	120.1	43.4

Source: Adapted from Guerrero (2020c). Rows 1, 2, 5: Eurostat (n.d.). Row 3: Bonfim et al. (2013); Danish Ministry of Higher Education and Science (n.d.), Government.no (n.d.). Rows 4, 5: Websites of the universities located in each region. Row 6: Direção-Geral de Estatísticas da Educação e Ciência (n.d.), Statistics Norway (n.d.), own elaboration from Statistics Denmark microdata. Row 7: Eurostat (n.d.). Row 8: European Commission (2019). The data for the Copenhagen metropolitan region corresponds to the Capital Region of Denmark. In rows 1, 2 and 6–8, the data for the Oslo metropolitan region corresponds to the counties of Oslo and Akershus. In row 6, the data for Rogaland corresponds to the sum of the Rogaland and Agder counties, and the data for Aveiro corresponds to the broader Centro Region.

Finally, in non-metropolitan university regions, a smaller proportion of the workforce is employed in medium- and high-technology manufacturing and knowledge-intensive services compared to metropolitan regions, as measured in the Regional Innovation Scoreboard. The smaller share of high-tech employees in non-metropolitan university vs metropolitan regions is also coherent with the characterisation, formulated in section 1.2.2, of the former as having a relatively small share of sectors that rely heavily on scientific research.

1.4. DATA SOURCES AND RESEARCH METHODS

The present thesis relies on a mixed methods approach. Quantitative research techniques, like those applied in papers B and C, allow to test hypotheses and reach generalizable conclusions; however, these analyses can only point to factors that are associated with the likelihood that firms collaborate with universities. Qualitative research techniques, like the semi-structured interviews applied in paper D, allow for a more in-depth understanding of the mechanisms underlying the statistical associations identified in the quantitative papers, exploring the role played by factors such as firms' external knowledge-sourcing strategy at different stages in the development of these partnerships.

The analyses from papers B and C—and partly paper A—rely on two quantitative databases provided by Statistics Denmark: The first is the integrated database for labour market research (IDA, in Danish), which is a register dataset that combines individual-level data on the Danish population with workplace-level data on the population of workplaces in Denmark (Timmermans, 2010). Using unique identification numbers allows to connect the IDA data to the second database, the Danish Research and Innovation survey. This is the Danish version of the CIS, which was introduced in Denmark in the 1990s and has been conducted on an annual basis since 2007 by Statistics Denmark. The CIS provides data on indicators, such as the types of innovation developed by firms, the types of organisations that firms cooperate with and the geographical location of these partners (Eurostat, 2014; Laursen and Salter, 2004; Statistics Denmark, 2015).

It should be noted that, whereas the IDA database encompasses the whole population of individuals and workplaces in Denmark, the Danish research and innovation survey does not. Each wave includes all firms in the population with more than 100 full-time equivalent employees (FTEs); below that number, the likelihood of being selected for a wave increases with the number of FTEs and the R&D intensity of the sector. On the other hand, the surveys are compulsory, which helps to minimise non-response (Statistics Denmark, 2015).

In paper A (Guerrero and Evers, 2018), a mixed methods approach was chosen in order to carry out a case study on how the interaction between a non-metropolitan university (Aalborg University) and specific industries in North Denmark might have contributed to the growth of these industries. On one hand, data from the IDA database allowed to conduct quantitative descriptive analyses on the evolution of the number of employees working in these industries, highlighting the points in time during the period studied (1980–2010) when the workforce grew. On the other hand, the case study also relied on secondary data and semi-structured interviews to explore how the educational, research and third-mission activities by Aalborg University relate to the growth trends highlighted in the quantitative analyses. The secondary data consisted of policy reports, press clippings and publications in academic journals. The interviews were conducted with stakeholders from the regional administration and regional cluster organisations. These interviews allowed to validate some of the insights gathered from the document data, while also providing complementary insights.

In papers B and C (Guerrero, 2020a, 2020b), a fully quantitative approach was chosen. Data from the IDA database and the Danish Research and Innovation survey were combined in order to test for statistical associations between the variables hypothesised to be relevant for firms' collaboration with universities, and firms' propensity to collaborate with universities, in the different types of regions in Denmark. Opting for quantitative analyses in these papers—namely, the use of logistic regression—was deemed a suitable approach because they helped test whether the factors of interest were positively associated with industry–university collaboration, and whether such associations were stronger in some types of regions than others.

The analyses carried out in papers B and C could only point to factors positively associated with industry–university collaboration and highlighted whether these associations vary by type of region. However, they could not explore how—and in what ways—such factors are positively associated with the development of specific collaborations. In order to compensate for the lack of insights offered by papers B and C, paper D (Guerrero, 2020c) followed a fully qualitative approach. A multiple case-study design was carried out to explore how the factors considered to be positively associated with industry-university collaboration in papers A–C relate to the inception of collaborations between firms and universities and how they could further develop at later stages. The multiple case study involved seven SMEs in the non-metropolitan university regions of North Denmark, Rogaland (Norway) and Aveiro (Portugal), currently engaged in collaboration for innovation with the universities of their region (Aalborg University, the University of Stavanger and the University of Aveiro, respectively). In order to highlight what traits are specific to SMEs in non-metropolitan university regions, four additional cases of SMEs in metropolitan regions are included.

Paper D is based on semi-structured interviews and archival data related to case studies of collaboration between specific firms and universities. The interviews were mainly conducted with managers of the firms involved in these collaborations who had been in charge of the relationships with the university partner during the partnership; therefore, they could provide information about the current state of the collaboration and how it evolved over time. In some cases, interviews were conducted with industrial PhD fellows employed at the firm who had been in charge of the collaboration project linking firm and university. Interviews were conducted, as well, with the university researchers involved in these projects whenever the firm managers could not provide information about the origins of the relationship with the focal university. Documents such as press clippings, websites or internal files provided by firm managers supplemented the information gathered from the interviews.

1.5. CONTRIBUTIONS OF THE THESIS

This section delineates the findings of each paper and how they provide, together, a contribution to the literature and to policy making.

1.5.1. JOINT CONTRIBUTION TO THE RESEARCH QUESTIONS, AND THE LITERATURE

Together, the papers contribute to the literature by providing findings in five aspects: the role that universities in non-metropolitan regions can play as *animateurs* (Uyarra, 2010, p. 1238) of industry–university collaboration for innovation in this type of region (RSQ1); the differences among the three region types in the association between graduate employment and industry–university collaboration (RSQ2), and between external knowledge-sourcing and industry–university collaboration (RSQ3).

In connection to RSQ1, the thesis findings provide empirical evidence supporting the view, expressed in the literature, that universities can promote innovation and economic development in their regions (Clark, 2004, 1998; Gjerding et al., 2006; Trippl et al., 2015b; Uyarra, 2010), in particular, in non-metropolitan regions (Alpaydin et al., 2018; Boucher et al., 2003; Nilsson, 2006; Rodrigues and Teles, 2017). They show that the educational, research and third-mission investments made by non-metropolitan universities might not, by themselves, trigger the expansion of high-technology industries and that these industries should be large enough to tap into university investments (paper A). Moreover, the thesis findings deepen the insights from the literature, showing that universities in non-metropolitan regions take a proactive role in establishing relationships with regional firms, at least with SMEs from sectors traditionally not reliant on university research. Universities in non-

metropolitan regions can start such relationships through institutional events organised by university management, but also because university researchers look for university partners. Student internships also provide a first link (see paper D).

Second, graduate employees appear to support industry–university linkages by providing firms with an understanding of university research (Drejer and Østergaard, 2017). In connection to RSQ2, paper B suggests that graduate employees' role as *intermediaries* between firms and universities appears to be stronger among firms in rural/peripheral regions compared to those in metropolitan regions; among firms that employ university graduates, businesses in rural/peripheral regions are more likely to collaborate with universities than are their metropolitan counterparts. These results indicate that firms in rural/peripheral regions benefit, in particular, from the knowledge of universities and university research that graduate employees can provide, compensating for the relatively long distances that separate firms in rural/peripheral regions from universities.

In connection to RSQ3, the thesis findings add a regional dimension to the observation that external knowledge sourcing is positively associated with industry–university collaboration (Hewitt-Dundas et al., 2019; Laursen and Salter, 2004), pointing to the role played by specific types of organisations. Paper B suggests that, among the different types of regions, there is a negative association between external knowledge-sourcing in general, measured as the number of types of a firm's knowledge sources, and firms' collaboration with universities. Paper C shows that collaboration with RTOs is positively associated with industry–university collaboration among firms in peripheral and metropolitan regions, but not among non-metropolitan businesses, perhaps because these regions are home to universities committed to establishing links with regional businesses[8]. Finally, among the non-metropolitan case firms compared in paper D, the desire to attract international customers incentivises the unfolding of industry–university links into full-fledged collaborations. To attract international customers, firms need to increase their product development capabilities and technical competencies; full-fledged collaborations with universities provide firms with an opportunity to fulfil this goal. More generally, the findings suggest that firms tend to be incentivised by a specific feasible goal if they decide to commit the effort required to develop links with universities into full-fledged collaborations. Note that in paper D, public funding sources—whether national or European, like H2020 funds—support firms in the resource investments they have to commit when building a relationship with the focal university. Thus, public funding supports the case firms' goals when strengthening connections to academia.

Altogether, the papers answer the main research question (*To what extent do the roles of key factors associated with industry–university collaboration differ across types of*

[8] In the other two types of regions, firms that collaborate with RTOs might acquire insights useful to learning to work with universities.

regions?) and contribute to the literature by pointing to the existence of regional variations in factors positively associated with industry–university collaboration. Regions differ in terms of their organisational thickness and diversity (Isaksen and Trippl, 2017; Trippl et al., 2018; 2015a), their suitability as labour markets for university graduates (Ahlin et al., 2014; Faggian and Mccann, 2009; Scott, 2010; Storper and Scott, 2009) and their degree of geographical isolation (Jakobsen and Lorentzen, 2015; Shearmur, 2015; Shearmur and Doloreux, 2016). The thesis papers presented here point out how variations in regional characteristics relate to the roles played by factors associated with industry–university collaboration.

A growing body of literature has found that non-metropolitan universities are developing an increasing range of education, research and third-mission activities to promote innovation in regional firms (Alpaydin et al., 2018; Boucher et al., 2003; Nilsson, 2006; Rodrigues and Teles, 2017). This thesis shows that the actions of non-metropolitan universities have to be met with large enough industries at the regional level, should they lead to the development of the focal industries. Below the level of regional industries, the thesis also suggests that the actions of non-metropolitan universities are key to establishing links with SMEs. Secondly, this thesis adds to the view that graduate employment is positively associated with industry–university collaboration (Drejer and Østergaard, 2017; Laursen et al., 2011) by suggesting that its relevance varies with the type of region. Namely, the role of graduate employment appears to be more relevant in rural/peripheral regions than in non-metropolitan and metropolitan regions. Third, the thesis contributes to the literature on industry–university collaboration and open innovation (Hewitt-Dundas et al., 2019; Laursen and Salter, 2004) by suggesting that a specific form of external knowledge-sourcing—collaboration with RTOs—is positively associated with industry–university collaboration in rural/peripheral regions and metropolitan regions, but not in non-metropolitan university regions. Furthermore, another form of external knowledge-sourcing—interaction with international customers—appears to incentivise firms to develop their links with universities into collaborative research.

1.5.2. LIMITATIONS AND FURTHER RESEARCH

The regional differences in the industry–university collaboration dynamics observed in the present thesis might be all the more relevant to the literature considering that most of the thesis relies on data from a small country, Denmark, where relatively short geographical distances between firms and universities might be conducive to industry–university collaboration. However, because the thesis does not include quantitative analyses with data from other countries, it is difficult to assess, empirically, whether the regional differences observed in papers B and C are dependent on geographical distance between firms and universities. Further quantitative research could assess whether the regional differences observed in papers

B and C (in the associations between graduate employment and industry–university collaboration, and between external knowledge-sourcing and industry–university collaboration) are transferable to larger, more sparsely populated countries.

Another limitation also concerns the characteristics of Denmark, as a country with a single metropolitan region, which is also its political capital. The governmental sector's demand for university-trained employees might make the Copenhagen metropolitan region a labour market more attractive to university graduates, compared to other non-metropolitan regions, thus endowing it with a higher proportion of graduate employees compared to cities that are not national capitals. In turn, firms that employ university graduates are more likely to collaborate with universities because graduate employees can provide them with an understanding of how universities operate as organisations (Drejer and Østergaard, 2017). Given the relative abundance of graduate employees in the Copenhagen metropolitan region, local firms might find it relatively easier to tap into graduate employees in order to collaborate with universities, compared to firms in other metropolitan regions. Hence, further research applying quantitative methods could assess whether the regional differences observed in papers B and C are transferable to countries with metropolitan regions beyond the political capital.

A third limitation stems from the fact that papers B and C study the relevance of graduate employment and external knowledge-sourcing strategies for firms' collaboration with one or more universities in Denmark, rather than collaboration with specific universities. Thus, it is not possible to consider whether differences in geographical proximity might make a firm more likely to collaborate with some universities than others. Further research could conduct analyses similar to those of papers B and C, replacing the current dependent variable—collaboration with one or more universities in Denmark—with a variable capturing whether firms collaborate with *specific* universities in Denmark. However, the total number of collaborations with each specific university, as defined in the thesis, is relatively low. This is particularly the case of some universities, as is visible in table 5, which is constructed based on the answers provided by the firms that participated in the 2016 wave of the Danish Research and Innovation Survey (Statistics Denmark, n.d.). The firms with the smaller number of partners are the Copenhagen Business School, Roskilde University and the IT University of Denmark. Exploring regional differences in firms' collaboration with specific universities would thus prove to be a challenging exercise.

A fourth limitation stems from the fact that the quantitative papers in the thesis cannot capture causal processes. The analyses carried out in papers B and C are based on cross-sectional datasets; thus, it is not possible to determine whether changes in the share of graduates that firms employ, or in their use of external knowledge-sources, are likely to lead, at a later point, to a higher propensity to collaborate with universities. In order to explore such causal relationships, further research could extend the analyses in papers B and C by combining two or more waves of the Danish

Research and Innovation Survey in a panel dataset. As in the previous suggestion for further research, the total number of observations with positive values in the dependent variable would be lower because only a fraction of firms responded to two or more consecutive waves of the survey (see the methods sections of papers B and C for further details).

Table 5: Number of firms that collaborate on innovation with each Danish university, 2016

Name of the university	Type of region where the university is located	Number of firms
Aalborg University	Non-metropolitan university	220
Aarhus university	Non-metropolitan university	215
University of Southern Denmark	Non-metropolitan university	162
University of Copenhagen	Metropolitan	172
Copenhagen Business School	Metropolitan	55
Technical University of Denmark	Metropolitan	281
Roskilde University	Metropolitan	24
IT University of Denmark	Metropolitan	21

Source: Statistics Denmark (n.d.)

A final set of challenges stem from the findings in paper D; these concern non-metropolitan SMEs operating in sectors that do not traditionally rely on university research, and they are not necessarily transferable to larger firms or firms that do not operate in the same type of sectors. Further case studies involving firms that are not SMEs and/or do not operate in sectors traditionally reliant on university research could help extend the transferability of the findings. Also concerning paper D, in the current formulation, a smaller number of cases involves SMEs in metropolitan regions; this number is sufficient to highlight findings specific to industry–university collaboration processes in non-metropolitan university regions, but not large enough to compare between firms in non-metropolitan university regions and metropolitan regions (see paper D for further details). Further research could also extend the findings from paper D by including more cases from metropolitan regions.

1.5.3. POLICY IMPLICATIONS

The findings from the thesis provide interesting suggestions for industry–university collaboration policies, including those that incentivise universities' involvement in

regional innovation and development and those that increase firms' incentives to collaborate with universities.

When analysing universities' involvement in regional innovation and development, the thesis papers suggest that the educational, research and third-mission activities carried out by non-metropolitan universities can contribute to the development of industries in their regions, provided that these industries have a critical mass at the start of the relationship with the focal university (paper A). Another finding is that industry–university links in non-metropolitan university regions tend to start because of the activities developed by the local universities (paper D). Drawing from the findings of papers A and D, schemes that provide financial support to non-metropolitan universities' regional engagement activities can further incentivise their inclination to devote educational, research and third-mission resources to the development of their regions. An example of such policies is the knowledge dissemination agreement between Aalborg University and the North Denmark's Growth Forum, a public–private council in charge of promoting projects related to innovation in the region (Lindqvist et al., 2012). Under this agreement, the Growth Forum provided funding to projects where the university supported innovation in regional firms.

Turning the focus to firms' incentives to collaborate with universities, policies should emphasize more clearly the incentives and goals of firms in different types of regions, when these firms establish linkages with universities and when they decide to develop these linkages into full-fledged collaborations. For instance, paper D suggests that the desire to attract international customers incentivised the non-metropolitan case firms to unfold their relationships with universities into full-fledged collaborations. Moreover, that these firms tapped into public funding schemes to finance collaboration with universities suggests that it is possible to design schemes that incentivize and motivate firms, helping them see in universities a research partner useful to their goals.

On that note, based on the present findings, existing policies could be repurposed to increase incentives for firms in rural/peripheral regions to collaborate with universities. While schemes like Innobooster in Denmark provide financial incentives to SMEs that wish to hire university graduates (Knudsen et al., 2018), an update of this approach could provide higher incentives to SMEs in rural/peripheral regions compared to those in other areas. The rationale for these *above-average* incentives to SMEs in rural/peripheral regions is found in the finding (paper B) that the association between firms' employment of university graduates and their collaboration with universities is stronger among firms in rural/peripheral regions compared to those in more densely populated regions. Second, innovation vouchers, like those used in Denmark (Knudsen et al., 2018), provide financial support to firms that wish to purchase research services from universities and RTOs, incentivising firms to establish links with such organisations. Based on the finding (paper C) that

collaboration with RTOs is positively related with collaboration with universities among firms in rural/peripheral regions, innovation vouchers could be targeted to these firms.

This is, admittedly, a brief summary of the policy suggestions that can be extracted from the thesis; scholars and practitioners interested in the papers might find additional policy suggestions. Either way, the present thesis supports the view that policies should take into account that universities develop their regional mission in different types of regions (Boucher et al., 2003; Nilsson, 2006). Accordingly, the policy toolkit used to promote industry–university collaboration should be suited to the characteristics of the region where firms are located, just like regional innovation policies have to be suited to different types of regions (Tödtling and Trippl, 2005).

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PART II: NON-METROPOLITAN UNIVERSITIES' ROLE IN REGIONAL INDUSTRIAL DEVELOPMENT

CHAPTER 2. PAPER A. CO-CREATION OF LOCALISED CAPABILITIES BETWEEN UNIVERSITIES AND NASCENT INDUSTRIES: THE CASE OF AALBORG UNIVERSITY AND THE NORTH DENMARK REGION

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2.1. ABSTRACT

This chapter 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 biomedical 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.

2.2. 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 and 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 chapter, 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 chapter 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 and 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 chapter 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, 2006; 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 chapter take place in a specific setting. What we propose in this chapter 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 chapter could be complemented with other case studies in order to identify empirical regularities, and potentially propose new theory (Tsang, 2013).

2.3. 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, p51) 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. 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 et al., 2017; Østergaard and Park, 2015).

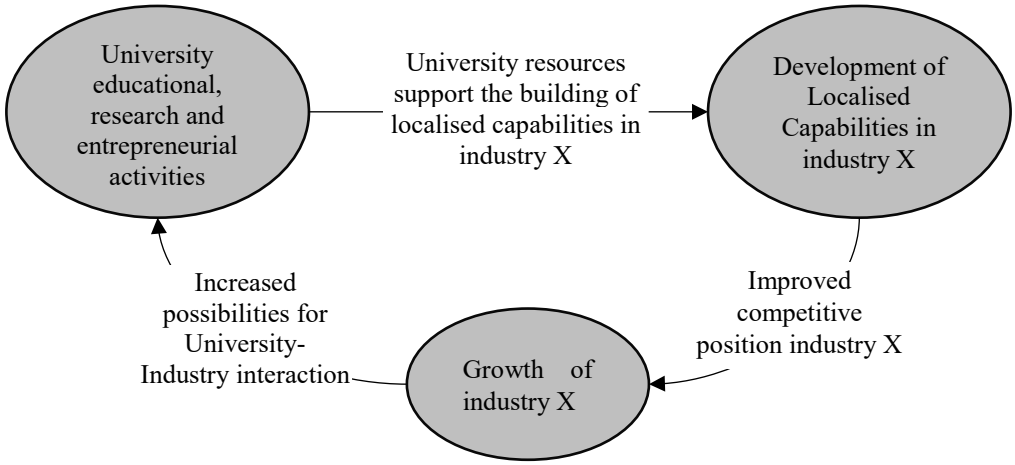
Cooperation between universities and businesses can also reinforce the development of localised capabilities. This should be especially the case for science-based industries since these are more dependent on the knowledge produced at universities, and hence on university activities (Pavitt, 1984). Drucker & 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 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) [9]. 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 1: Conceptual model of the creation of localised capabilities through university-industry interaction



Source: Own ellaboration

In our analysis, we aim to focus on the stages depicted in the shaded ovals in figure 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

[9] 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[11].

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 chapter (Nilsson, 2006; Stoerring, 2007; Stoerring and 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 development 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 chapter.

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.

2.4. METHODOLOGY

This chapter 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 et al., 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., 2014a; Laursen et al., 2011; Rodríguez-Pose and Fitjar, 2013), the present chapter 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 and 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[10] 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[11], 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 for a list of the industry groupings included).

[10] 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 and Polavieja, 1997).

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

2.5. AALBORG UNIVERSITY: CREATING AND BEING SHAPED BY LOCALISED CAPABILITIES

2.5.1. 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, 2006; 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.; Nilsson, 2006; 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 (see for further context box 1). 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, 2006). Over time the university experienced rapid growth, and with 20,654 students in 2017, it is the fifth-largest higher education institution in Denmark (Aalborg University, n.d.).

Box 1: 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, 2006; Pedersen, 2005).Within this context, AAU started as a university combining a technical imprint with a large share of degrees 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%).

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.

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, 2016; 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, pp. 249–250) 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.

2.5.2. CASE 1: AAU ADAPTS (AND SUPPORTS) ACTIVITIES RELATED TO THE ICT INDUSTRY

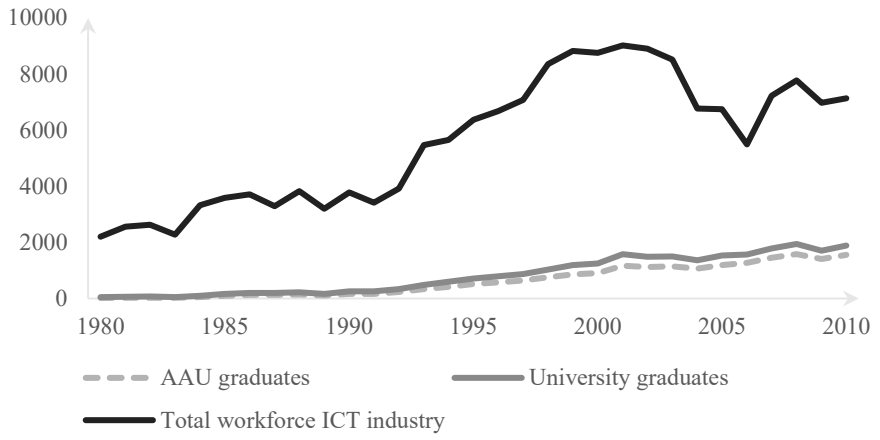
The 1980s and 1990s saw the expansion of the ICT industry in North Denmark. According to the IDA database, the industry workforce increased from 2,203 to 3,786 jobs between 1980 and 1990 and reached a peak of 9,022 employed persons by 2001[12] (see figure 2). These developments reflected the rapid expansion 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

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

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.

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 and 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, n.d.). The firms in the ICT industry tapped into AAU's educational and research activities to acquire human capital and increase their innovation capacity.

Figure 2: Number of employees in North Denmark's ICT industry

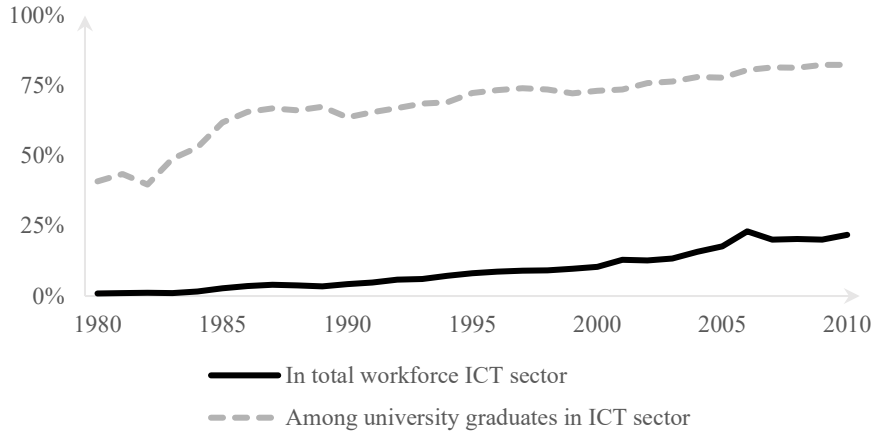


Source: Own elaboration with data from Statistics Denmark

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 2 indicates a growing number of university

graduates employed in the ICT industry, while the dashed grey-line in figure 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 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 and 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, 2006; Stoerring, 2007; Stoerring and 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 and 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 and 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[13], 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

[13] 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).

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 and 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 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 and 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 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 and 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 & Østergaard (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 2 and 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, n.d.), 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.). 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.

2.5.3. CASE 2: ATTEMPTS TO SUPPORT ACTIVITIES RELATED TO THE BIOMEDICAL INDUSTRY

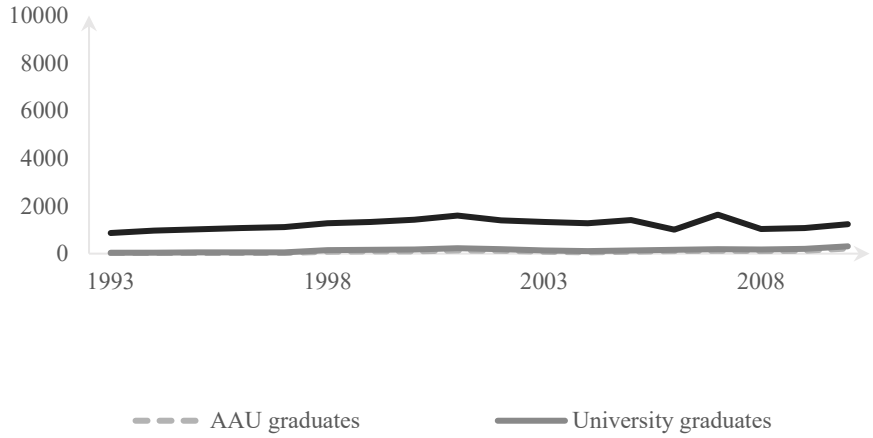
When the activities of AAU in support of the biomedical industry started in the early 2000s, this industry was at an earlier stage of development compared to the ICT industry and had not reached a critical mass similar to that of ICT. These differences appear to explain why the support activities developed 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 and 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 and 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 and 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 and 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 and Dalum, 2007). The analysis of the IDA database (figure 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 and Dalum, 2007). This has been the case despite a further analysis with the IDA database (see figure 5) suggests an increasing involvement of AAU graduates, approaching the levels of the ICT firms.

Figure 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, n.d.). 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, n.d.; Thomson Reuters, n.d.).

Figure 5: Share of AAU graduates in North Denmark's biomedical industry (excl. hospital)

Source: Own elaboration with data from Statistics Denmark

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 (Stoerring, 2007; Stoerring and Dalum, 2007) 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 also argued that the activities developed by AAU; and the acquisition of a university start-up (Neurodan) by a German firm (Otto Bock) might trigger the expansion of the industry in the region[14]. However, the analysis of the IDA database up to 2010 (figures 4 and 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.).

[14] Stoerring(Stoerring, 2007; Stoerring and Dalum, 2007) focused on processes of cluster growth, and hence her research differed from industry studies. Clusters, in fact, can include 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.

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[15] (Hopkins et al., 2007; Østergaard et al., 2017; Østergaard and Park, 2015; Welch et al., 2011). 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.; Thomson Reuters, n.d.).

2.6. 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.

[15] 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 and Dalum, 2007). Another reason is to ensure that the region retains a university hospital (interview regional expert)

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

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 (Stoerring, 2007; Stoerring and Dalum, 2007), who observed weaker growth dynamics in the biomedical firms of North Denmark than in their ICT counterparts, until the mid-2000s. 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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Disclosure statement

Declarations of interest: none.

Appendix: Variables used in the 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).

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
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)
	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 photographic equipment (267), Manufacture of wiring and wiring devices (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), Manufacture 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, computer 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)
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

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PART III: THE ROLE OF GRADUATE EMPLOYMENT AND EXTERNAL KNOWLEDGE SOURCING FOR INDUSTRY-UNIVERSITY COLLABORATION, IN DIFFERENT TYPES OF REGIONS

CHAPTER 3. PAPER B. INDUSTRY–UNIVERSITY COLLABORATION IN RURAL AND METROPOLITAN REGIONS: WHAT IS THE ROLE OF GRADUATE EMPLOYMENT AND EXTERNAL NON-UNIVERSITY KNOWLEDGE?

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3.1. ABSTRACT

This study examined to what extent graduate employees' cognitive proximity to universities and firms' external knowledge acquisition strategies are positively associated with the likelihood that firms in rural and metropolitan regions collaborate with universities in Denmark. These links were explored using a dataset that combined data from the Danish Research and Innovation Survey with Danish register data. The results pointed to a positive association between firms' employment of graduates and industry-university collaboration, which was stronger among firms in rural regions than firms in the Copenhagen metropolitan region; however, drawing on external non-university knowledge was similarly associated to industry-university collaboration among firms in rural regions and in the Copenhagen metropolitan region. Regardless of their location, firms were more likely to collaborate with universities if they collaborated with other organisations and were less likely to collaborate with universities if they sought knowledge from other sources, even without necessarily collaborating with them. Although firms in rural regions tended to be farther away from universities than firms in the Copenhagen metropolitan region, the former might be able to collaborate with universities because graduate employees can provide firms with a better understanding of the research conducted there. Thus, firms in rural regions might not need to be geographically proximate to universities in order to collaborate with them.

3.2. INTRODUCTION

Universities are expected to contribute to the economic development of their regions by supporting the efforts of local firms to innovate. In particular, policymakers have promoted the regional missions of universities beyond metropolitan centres in the hope of supporting economic development outside urban agglomerations (Charles, 2006; Evers, 2019; Nilsson, 2006).

Differences in regional characteristics, however, also entail differences in the environments in which industry–university collaboration takes place. Rural regions are more sparsely populated than metropolitan regions and tend to have fewer knowledge-generating organisations such as universities (Tödtling and Trippl, 2005). Furthermore, the university presence in rural regions tends to be limited to a few branch campuses (Charles, 2016). Thus, firms in rural regions typically have to overcome a larger geographical distance to collaborate with universities (Johnston and Huggins, 2016).

Because firms that are geographically closer to universities have been found to be more likely to collaborate with universities than firms that are farther away, owing to the advantages of geographical proximity in facilitating the transmission of complex, tacit knowledge through face-to-face interactions (D'Este et al., 2013; D'Este and Iammarino, 2010; Drejer and Østergaard, 2017), geographical distance might pose an obstacle to industry–university collaboration for firms in rural regions. The relative absence of universities in rural regions might also imply that universities are less likely to become a usual collaboration partner among firms in rural regions.

However, forms of proximity other than geographical might be more relevant for determining how inter-organisational collaboration takes place (Boschma, 2005). In particular, firms have been found to be more likely to collaborate with universities if they employ graduates from that university, suggesting that graduate employees can facilitate cognitive proximity between their current employers and universities by providing firms with a deeper understanding of university research and how universities function as organisations, increasing the ability of firms to integrate university knowledge (Drejer and Østergaard, 2017). However, little is known so far on how the relationships between graduate employment and industry–university collaboration might differ between firms in rural regions and their metropolitan counterparts.

Secondly, although firms that draw on external non-university knowledge have been found to be more likely to collaborate with universities (Hewitt-Dundas et al., 2019; Laursen and Salter, 2004), little is known on how drawing on this knowledge might differently affect industry–university collaboration among firms in rural regions and those in metropolitan regions. Previous research has found that firms in sparsely populated locations were more likely to rely on collaboration channels with other

organisations than firms in densely populated locations. By collaborating with these organisations, firms in sparsely populated locations might gain access to knowledge that cannot be acquired through unplanned, informal interactions in their home regions (Jakobsen and Lorentzen, 2015). These collaboration channels can also entail extra-regional partners, if no suitable partners are to be found in their home region (Drejer and Vinding, 2007; Grillitsch and Nilsson, 2015).

This paper's initial aim was to contribute to the industry–university collaboration literature by exploring the links between graduate employment and industry–university collaboration in innovation among firms in rural regions and firms in metropolitan regions. A second aim was to compare, between firms in rural and metropolitan regions, the relationship of drawing on external non-university knowledge to industry-university collaboration in innovation. In doing so, the following research question was addressed:

To what extent are graduate employment and drawing on external knowledge net of universities associated with collaboration in innovation between universities and firms in rural and metropolitan regions?

To date, few papers have compared how industry–university collaboration takes place in different regional contexts. In particular, not much is known about how industry–university collaboration takes place in rural regions relative to other types of regions (Johnston and Huggins, 2016); the literature is mostly focused on factors associated with industry-university collaboration regardless of the regional location (D'Este et al., 2013; D'Este and Iammarino, 2010). This paper helps to close this gap by using a dataset that combines research and innovation survey data and register data for 4,772 firms in Denmark involved in conducting innovation activities between 2009 and 2015. With this dataset, logistic regression analyses were performed on the likelihood that firms collaborate with universities located in Denmark.

The study adds to the industry-university collaboration literature by confirming that there was a positive association between graduate employment and industry-university collaboration in innovation, but this association was stronger among firms in rural regions than their metropolitan counterparts. Secondly, firms in rural regions that drew on external knowledge net of universities were not more likely to collaborate with universities in innovation than similar firms in metropolitan regions.

By relying on the cognitive proximity of graduate employees to university research, firms in rural regions appeared to overcome the obstacles that their location might pose to industry–university collaboration in innovation. Conversely, the co-location of firms and universities might be enough to facilitate industry-university collaboration in innovation in metropolitan regions. There is also the possibility that graduate employees' social ties to staff from their *alma mater* universities facilitate collaboration with these universities. However, the dataset used in the present paper

did not allow for testing this possibility, and further research would be required. Policymakers interested in facilitating the involvement of firms in rural regions in industry–university collaboration might see in graduate employment a channel through which more of these firms could benefit from collaboration with universities.

The paper is structured as follows. The next section presents the literature review and hypotheses. Afterwards, the research methods used in the paper are outlined. A third section presents the empirical analyses. Finally, the concluding section discusses the main findings of the paper.

3.3. LITERATURE REVIEW

3.3.1. HOW CAN GRADUATE EMPLOYEES CONNECT FIRMS IN RURAL AND METROPOLITAN REGIONS WITH UNIVERSITIES

Firms in rural and metropolitan regions operate in different regional environments, and these differences can have consequences for a firm's innovation activities. Tödtling and Trippl (2005) and Zukauskaite et al. (2017) point out that firms in rural regions operate in organisationally thin regions, with few or no urban agglomerations and a narrow variety of knowledge-generating organisations, such as universities. The characteristics of metropolitan regions are markedly different because these are predominantly urban, organisationally thick and diverse regions; home to a broad range of knowledge-generating organisations. Indeed, Charles (2016) shows that in rural regions university presence tends to be limited to a few branch campuses.

These inter-regional differences mean that firms in rural regions might face (when compared to firms in metropolitan regions) an obstacle to industry–university collaboration because geographical proximity has been observed to facilitate collaboration between firms and universities, owing to the role of geographical proximity in enabling face-to-face contacts between partners. D'Este et al. (2013) and D'Este and Iammarino (2010) suggest that frequent face-to-face encounters can facilitate the transmission of complex and tacit knowledge between firms and universities and can prevent misunderstandings that might emerge when trying to align the routines of the firms and universities. Furthermore, the relative absence of universities in rural regions might imply that these institutions do not appear to firms in these regions as feasible collaboration partners, at least not as readily.

However, geographical proximity is not a necessary condition for the transmission of knowledge between two or more parties, and other forms of proximity might suffice. Aguiléra et al. (2012) and Boschma (2005) argue that knowledge transmission is feasible among organisations that are cognitively proximate, that is that they possess similar knowledge bases; the same goes for organisations that are socially proximate,

those that share social ties and therefore can more easily establish trust-based relationships. Nevertheless, these two forms of proximity facilitate knowledge transmission in different ways. When two parties are cognitively proximate, the similarity enables them to better understand each other's knowledge base. Furthermore, the compatibility between the parties' knowledge bases suggests that it will be easier for them to integrate the knowledge they exchange. Meanwhile, when two organisations are socially proximate, trust-based relations between employees in the two organisations enable the transmission of complex knowledge because the parties can commit to the effort required to facilitate the transmission of this knowledge beyond the dictates of market incentives.

Based on the previous discussion, geographical proximity might not necessarily be a requirement for knowledge transmission between firms and universities and the use of industry–university collaboration to transmit knowledge between firms and universities. The industry–university collaboration literature has pointed out that graduate employees can help in connecting firms and universities (Breschi and Lissoni, 2001; Drejer and Østergaard, 2017; Østergaard, 2009). Østergaard (2009) argues that engineers educated at a nearby university or that have collaborated in projects with researchers from it are more likely to have informal contacts with the university. The networks these engineers maintain with a focal university, he argues, allow the engineers to have knowledge of which research is being conducted there and which researchers from that institution they can approach. Thus, engineers are key to firms because they help the firm understand university knowledge—providing cognitive proximity—and also because their social networks enable the firm to know which university researchers should be approached, contributing to the social proximity between their employers and the university where they obtained their degrees.

Similarly, Drejer and Østergaard (2017) observed that firms are more likely to collaborate with a specific university if they have employees that hold a degree from that university. These findings were interpreted by Drejer and Østergaard (2017) as an indication that graduate employees can provide social proximity between their firms and the universities where they obtained their degrees because graduate employees can help firms approach university staff through their social networks; thanks to employee social ties, firms have an idea of who is who at the university. In addition, a certain university may be preferred over others in a discipline in which it specialised if employees hold degrees from this discipline; a finding that Drejer and Østergaard (2017) interpret as an indication that graduate employees' discipline-related knowledge can enable similarities between the knowledge bases of the focal firm and the university in terms of specific, discipline-related cognitive proximity.

Metropolitan regions are argued to have, relative to rural regions, a higher density of university graduates in their workforce because of various factors, such as the presence of pools of specialised labour serving agglomerated industries that provide

a better match between graduates' job searches and employer needs (Rodríguez-Pose and Fitjar, 2013; Scott, 2010; Storper and Scott, 2009); a more open, tolerant environment in cities, which might be attractive to university-trained professionals (Florida, 2002); and a greater concentration of emerging, high-technology sectors that demand employees with university qualifications (McCann, 2008; Storper, 2018). However, in metropolitan regions, geographical proximity might suffice for industry–university collaboration to take place because firms in these areas are typically co-located with more than one university. In contrast, for firms in rural regions, it might be more relevant whether they employ university graduates because these firms are not co-located near universities. Because of their university education, graduate employees might provide these firms with knowledge of university research and how universities function as organisations. Thanks to this knowledge, firms in rural regions that employ university graduates might be cognitively proximate to universities and so, are able to interpret and absorb university knowledge. The first hypothesis summarises this distinction:

H1: There is a positive association between employing university graduates and the likelihood of collaborating in innovation with universities, and this association is stronger among firms in rural regions than for similar firms in metropolitan regions.

Based on the previous discussion, it is also possible that graduate employees possess social ties to staff from their *alma mater* universities, providing social proximity between these universities and the firms where they are currently employed; however, the dataset used in the present paper does not contain information on social ties between firms and specific universities (see section 3.4). Therefore, the hypothesis does not explore the relevance of social ties between firms and universities for industry-university collaboration.

3.3.2. THE ROLE OF DRAWING ON EXTERNAL KNOWLEDGE NET OF UNIVERSITIES

Firms draw on external knowledge to increase their capacity to innovate (Criscuolo et al., 2018; Laursen and Salter, 2006; Rosenkopf and Nerkar, 2001). Within this literature, Laursen and Salter (2004) have also found that those firms that seek knowledge from a diversity of sources other than universities are also more likely to draw knowledge from universities. These other sources might include other firms (such as suppliers, customers, and competitors) but also may be public research organisations and sources other than organisations (such as conferences and the technical press). More recently, Hewitt-Dundas et al. (2019) have argued that by drawing knowledge from other organisations that are not universities, firms can develop knowledge-acquisition capabilities and cognitive proximity to universities. This is because collaborations with third-party organisations increase the stock of knowledge available to firms, and the greater the knowledge stock, the greater a firm's capacity to integrate further knowledge is. In addition, collaboration experience

increases a firm's ability to select those partners that fit best its knowledge needs. In this way, firms are cognitively closer and more likely to collaborate with universities.

Jakobsen and Lorenzen (2015) contend that firms in rural regions will show a stronger preference for formalised collaboration channels, because drawing on external knowledge through unplanned, informal interactions is less likely to be an effective strategy for innovation in regions with a limited stock of knowledge-generating organisations. That is, unplanned interactions are less likely to take place in regions with few knowledge-generating organisations. Conversely, in organisationally dense regions like metropolitan areas, informal interactions might suffice for obtaining knowledge. Furthermore, Drejer and Vinding (2007) argue that there are inter-regional differences in firms' propensities to collaborate for innovation with extra-regional organisations, finding that in sparsely populated locations firms with high levels of absorptive capacity—that is, the capacity to acquire, assimilate and integrate new knowledge (Cohen and Levinthal, 1990)—were more likely to have their main collaboration partner abroad. These extra-regional collaborations can compensate for the lack of suitable partners in the firm's region, and allow firms to gather knowledge not available in the region in which they are located. Similar arguments are proposed by Grillitsch and Nilsson (2015), who found that among firms of a relatively large size and absorptive capacity[16], those in locations with a sparse population of professionals working on technology-related fields were more likely to have formal collaboration arrangements than firms in more densely populated regions, and these collaboration arrangements were more likely to involve extra-regional partners.

By collaborating with organisations other than universities, firms might develop knowledge-acquisition capabilities and thus cognitive proximity to universities. Hence, industry–university collaboration might be more likely for both firms in rural and metropolitan regions if they have collaboration channels to acquire external non-university knowledge. However, firms in rural regions are more likely to rely on these channels than their metropolitan counterparts. Because geographical proximity is less likely to support firms in rural regions' collaboration with universities, it is more likely that firms in rural regions that collaborate with universities do so because they draw on external non-university knowledge, which also contributes to their cognitive proximity to universities. The second hypothesis summarises these arguments:

H2: There is a positive association between drawing on external knowledge net of universities and collaborating in innovation with universities, and this association is stronger among firms in rural regions than among similar firms in metropolitan regions.

[16] Measured as the proportion of employees in the firm with a high level of technological competences (Grillitsch and Nilsson, 2015, pp. 306–310).

3.4. RESEARCH METHODS

3.4.1. DATA SOURCES

In this paper, data are combined from two datasets managed by Statistics Denmark: the integrated database for labour market research (IDA, in Danish) and the Danish Research and Innovation Survey, which is the Danish version of the Community Innovation Survey. The IDA is a register dataset that combines personal-level data on the Danish population with data on the population of workplaces in Denmark (Timmermans, 2010).

The percentage of firms that collaborate with Danish universities as part of their innovation activities has fluctuated between 2009 and 2015 with a tendency for higher collaboration in even years and lower in odd years, for example, shifting from 12% in 2014 to 9% in 2015 (Erhvervsstyrelsen, n.d.). A likely cause for this variation is the design of the Danish Research and Innovation Survey questionnaires; during odd years, the questionnaires include more questions about research and development (R&D) activity, and a lower number of firms appear to report collaboration with universities as a likely result of respondent fatigue[17]. Taking into account that the firms' propensity to report collaboration with universities can vary from year to year, a pooled sample approach was chosen in this study. The following waves of the Danish Research and Innovation Survey were included: the 2011 wave, where firms were asked for data covering collaboration during the 2009–2011 period; the 2012 wave, covering 2010–2012; the 2013 wave, covering 2011–2013; the 2014 wave, covering 2012–2014; and the 2015 wave, covering 2013–2015. The combined dataset covered the time period from 2009 through 2015. Because the final sample was a merger of cross-sections, in this study, it was not possible to study causal relations.

Each wave included all the firms in the population with more than 100 full-time equivalent employees (FTEs). The lower the number of FTEs, the lower the likelihood of being selected for a wave. The surveys were compulsory, minimising the number of non-responses (Statistics Denmark, 2015, 2012) [18]. When constructing the combined dataset, the firms were selected so that they occurred only once. This was done by ordering observations according to their identification number. An assigned random digit was then assigned, and in a subsequent step, observations with repeated

[17] This pattern is reproduced in practically all the years in the time series reported by Erhvervsstyrelsen (n.d.). The only exception appears to be in the shift between 2012 and 2013, since the percentage of firms that reported collaboration with universities was the same between these two years, probably because of the crisis that affected Denmark in those years.

[18] Statistics Denmark derives its statistical population from the Business Statistical Register, defining a frame of enterprises and deleting certain activities and firms with few employees. The final frame population was also weighted (Statistics Denmark, 2015, 2012).

identification numbers were excluded. Through this procedure, only one observation per firm was included in the combined dataset, and the firms from one wave were not more likely to be included than firms from other waves.

After excluding repeated observations and excluding firms that did not engage in innovation activities[19] as well as firms that had missing or extreme values, the final combined dataset had 4,772 observations of which 955 corresponded to the 2011 wave, 909 to the 2012 wave, 919 to the 2013 wave, 931 to the 2014 wave and 1,015 to the 2015 wave. When analysing the dataset, the calibre weights provided by Statistics Denmark were applied (Månsson and Stoltze, 2011, pp. 78–80).

3.4.2. DEPENDENT VARIABLE

Binomial logistic regressions were run on the likelihood that firms reported having collaborated with one or more Danish universities (*COLLAB_UNI*). The data for the variable was obtained from the Danish Research and Innovation Survey, taking the value "1" if the firm reported collaborating with one or more universities and also reported these collaborations to be relevant to its innovation activities or "0" otherwise.

3.4.3. EXPLANATORY VARIABLES

To test Hypothesis 1, the study included a variable capturing the percentage of employees in the firm that held a university degree (*SHAREGRAD*), a variable capturing the focal firm's type of region (*REGION*) and an interaction term (*REGION*SHAREGRAD*). The data for *SHAREGRAD* and *REGION* were obtained from the IDA database. For each observation, *SHAREGRAD* was the percentage of employees holding a university degree in a firm averaged for all the years included in a wave of the Danish Research and Innovation Survey (e.g., for a firm that participated in the 2011 wave, *SHAREGRAD* was the average percentage of graduates in their workforce between 2009 and 2011). The graduate employees might have obtained their degrees in a Danish university or abroad. For the 2014 and 2015 waves, *SHAREGRAD* was an average of the years between 2012 and 2013 because the data required to construct the variable were only available until 2013; however, a comparison of the average and median values of *SHAREGRAD* across the years did not indicate substantial variations over time (those statistics are not presented in this

[19] These are the introduction of new or significantly improved products, manufacturing processes, operations, organizational structures or marketing techniques, as well as ongoing or abandoned innovation activities during the survey period.

paper). The data for *REGION* only covered the location of the focal firm in the last year of each wave, but a firm's location was not expected to change substantially on a year-by-year basis. *SHAREGRAD* has also been previously used as a proxy for a firm's absorptive capacity (Drejer and Østergaard, 2017); however, *SHAREGRAD* differs from other variables used to control for a firm's absorptive capacity (see below) in that graduate employees can provide knowledge of how universities function as organisations because of their university education. By employing university graduates, firms should be better able to understand how to interact with universities and thus, be cognitively closer to university research.

Whereas *SHAREGRAD* was used in the present paper to assess whether graduate employees contributed to the cognitive proximity between firms and universities, this variable was not used to capture whether graduate employees contributed to the social proximity between these types of organisations. Although it might be the case that firms are more likely to collaborate with specific universities because of the social ties between graduate employees and researchers from their *alma mater* universities, *SHAREGRAD* could not discern whether these social ties were in place and contributed to the social proximity between firms and universities. Hence, in this study, any results concerning *SHAREGRAD* were interpreted in connection to the role played by graduate employees in overcoming cognitive distance to universities.

Previous industry–university collaboration research has operationalised the ways firms draw on external non-university knowledge by counting the number of types of knowledge sources, whether these were organisations or not, that a firm might source knowledge from on an arm's length basis, though not necessarily involving collaboration (Laursen and Salter, 2004). Another approach involves counting the number of types of organisations and the net of universities that a firm collaborates with as part of its innovation activities (Drejer and Østergaard, 2017). Just as collaborative relationships between firms and universities require more commitment from the firm than industry–university links where there is no collaborative relationship (Perkmann and Walsh, 2007), collaborative relations might require the firm to commit more resources than drawing on external knowledge through arm's length non-collaborative relations.

To test Hypothesis 2, both approaches to drawing on external non-university knowledge were applied. The number of types of organisations, net of universities, public research institutes and approved technological services institutes that a firm collaborated with as part of its innovation activities were calculated (*COLLAB*); the number of types of sources, whether these were organisations or not, that a firm drew knowledge from, on an arm's length basis, excluding universities, public research institutes, scientific journals and conferences was also calculated (*SOURCE*). The data for these variables were gathered from the Danish Research and Innovation Survey, where respondents were asked to report whether their firms considered items from a list of knowledge sources as relevant to the firm's idea development activities

and the completion of innovation activities. *SOURCE* included: clients, suppliers, competitors, consultants and professional/industrial organisations. Responses for each of these sources were added so that "5" corresponded to firms that considered all types at least somewhat important. In the survey, respondents also had to report whether their firms collaborated with a list of different types of organisations as part of their innovation activities. *COLLAB* included: suppliers, customers, competitors, firms in other industries, consultants, public service providers and other public partners. Values for *COLLAB* ranged from "0" to "7", depending on the number of types of organisations with which firms collaborated. Both *COLLAB* and *SOURCE* interacted with *REGION.* The low correlation between *COLLAB* and *SOURCE* ($r = 0.19$, statistically significant below the 1% threshold) suggests that they fulfil different functions in a firm's innovation strategy. Indeed, based on the points raised by Jakobsen and Lorenzen (2015), one could argue that *SOURCE* corresponds to unplanned informal forms of knowledge acquisition. However, *SOURCE* is more likely to include planned interactions because the firm respondents were able to note the number of knowledge source types from which they drew.

REGION was operationalised as a categorical variable, capturing whether the firm's main workplace was located in a rural region, a metropolitan region or an intermediate region (i.e., a region with a population density in between that of typical rural and metropolitan regions). The benchmark corresponded to firms in a metropolitan region. Firms in intermediate regions were more likely to be co-located with universities than firms in rural regions because intermediate regions tended to have main university campuses (Isaksen and Trippl, 2014; Nilsson, 2006). However, the focus in the remainder of this paper is on the differences between firms in rural and metropolitan regions, because the research question and hypotheses focus on industry-university collaboration in rural and metropolitan regions.

The classifications used in *REGION* were based on the list of the functional urban areas of Denmark provided by the OECD, which also includes the municipalities comprising these urban areas (OECD, n.d.). The OECD defines a functional urban area as a location with at least 50,000 inhabitants, including a core of densely populated contiguous municipalities in which at least 50% of the area has a population density equal to or above 1,500 inhabitants/km^2 and an urban hinterland of municipalities in which at least 15% of the employed population commutes to work in the core municipalities[20]. The OECD defines a functional urban area with 500,000 inhabitants or more as a metropolitan area (OECD, 2012, pp. 29–34).

[20] To determine whether a municipality could be considered part of the core of densely populated municipalities, its area was divided into cells of 1 km^2. If 50% of these cells had population densities above 1,500 inhabitants per km^2, the municipality was considered part of this category (OECD, 2012, pp. 26–27).

In Denmark, the OECD (n.d.) identified five functional urban areas, which were from the largest to the smallest, Copenhagen, Aarhus, Odense, Aalborg and Esbjerg. With an average population of 1,839,146 inhabitants between 2009 and 2015, Copenhagen was the only metropolitan area. At the other extreme, the Esbjerg area had an average population of 168,528 inhabitants between 2009 and 2015 (Statistics Denmark, n.d.)[21]. The municipalities of the Copenhagen metropolitan area were categorised as a metropolitan region, and the municipalities in the other functional urban areas were intermediate regions. Finally, those municipalities that did not belong to any functional urban area were categorised as rural regions. Figure 1 shows the location of each type of region, and Table A1 in the Appendix provides a list of the municipalities included in each functional urban area.

The traits of the rural regions differed from those of the intermediate regions and the Copenhagen metropolitan region. Macro data from Statistics Denmark revealed an average population density between 2009 and 2015 of 79.22 inhabitants/km^2 for the rural municipalities, 130.93 inhabitants/km^2 for the intermediate municipalities and 775.15 inhabitants/km^2 for the metropolitan municipalities (Statistics Denmark, n.d.). Secondly, Figure 1 shows that the rural regions did not have main university campuses. All the intermediate regions except Esbjerg had main university campuses, and the Copenhagen metropolitan region had five universities (Danish Ministry of Higher Education and Science, n.d.). More differences are shown in the descriptive statistics below.

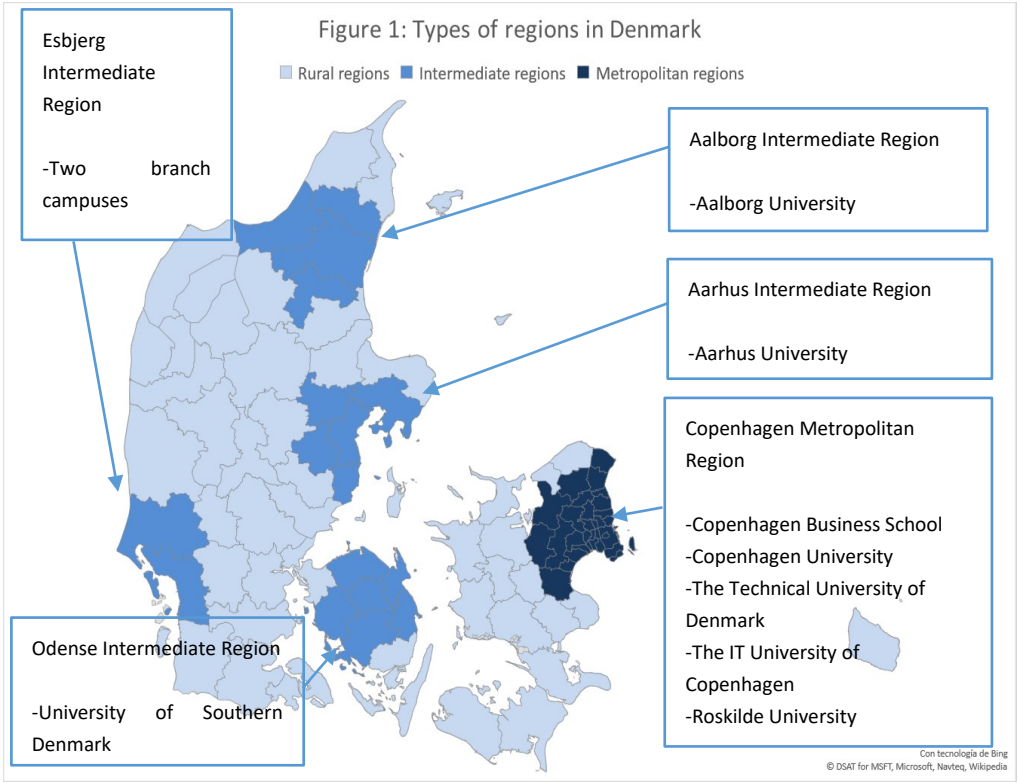
3.4.4. CONTROL VARIABLES

The analyses control for the use of internal knowledge sources (Criscuolo et al., 2018; Laursen and Salter, 2006) by including *SOURCE_INT*, which was based on data from the Danish Research and Innovation Survey. Its values were "0" if internal knowledge sources were not considered important for the firm's idea development activities, "1" if they were considered somewhat important and "2" if very important[22]. The

[21] In January 2019, the OECD list of functional urban areas for Denmark (OECD, n.d.) was updated, no longer including the Esbjerg area; however, the paper used the previous list because the data cover the 2009-2015 period.

[22] An earlier version of this paper included two variables, one capturing whether the firm saw internal knowledge sources as at the least a bit important and the other capturing whether the firm saw internal knowledge sources as very important. However, these have been merged to prevent multicollinearity issues.

benchmark was "1", because the size of the category was large enough to be a reference category[23].



Sources: Danish Ministry of Higher Education and Science, n.d.; OECD, 2012, n.d.

Firms that draw on external non-university knowledge also tend to draw on knowledge from universities (Laursen and Salter, 2004). To control for the propensity of firms to draw knowledge from universities or similar sources, the regression models included *SOURCE_ACADEMIC*, which controlled for arm's length knowledge sourcing, and *COLLAB_ACADEMIC*, which controlled for collaborative links. Both were based on data from the Danish Research and Innovation Survey. In

[23] 31.27% of the firms reported that internal knowledge sources were somewhat important to them.

SOURCE_ACADEMIC, firms that considered universities, journals or conferences at least somewhat important for idea development activities were coded as "1", or "0" otherwise[24]. In *COLLAB_ACADEMIC,* firms were coded as "1" if they collaborated with public research institutions and/or approved technological services institutes[25], or "0" otherwise.

DISTANCE controlled for a firm's geographical proximity to the nearest university. Inspired by Boschma et al. (2014), it was based on the logarithm of the road travel time in minutes between the postcodes of the focal firm and the closest university. This logarithm was subtracted from the highest value in the dataset so that "0" corresponded to the firms that were the farthest away from universities. The data used to construct *DISTANCE* were drawn from IDA.

The logistic regressions also included controls for the firms' structural characteristics. The values for the variables obtained from IDA were based on the data for the largest workplace in each firm:

- Two absorptive capacity controls were included: *RDSALES*, a firms' spending in R&D as a percentage of sales (Laursen and Salter, 2004); and *PATENTS,* which took a value of "1" for firms that reported applying for patents (Mohnen and Hoareau, 2003). The data for *PATENTS* was obtained from the Danish Research and Innovation Survey, and *RDSALES* was based on data from this survey and IDA. *RDSALES* only covered the last year for each wave in the survey because the question on which this variable was based only covered the last year of each wave; however, a comparison of average and median values of *RDSALES* across waves indicated that the firms' R&D intensity did not change substantially over time (those statistics are not presented in this paper). Those firms that reported R&D spending levels equivalent to more than 50% of their sales were excluded, as in Mohnen and Hoareau (2003).

- The logarithm of the total number of employees (*LOGFIRMSIZE*) was used as a proxy for firm size (Laursen and Salter, 2004). The data were obtained from IDA and represent an average for the period covered in each wave.

[24] Originally, the variable ranged from "0" to "2", counting whether firms collaborated with one or both types of organisations. However, the number of observations was too small for each level of the variable.

[25] These are government-approved, not-for-profit institutes focused on diffusing new technologies among the Danish industry. As part of their mission, they combine applied research with the provision of services to businesses, such as consultancy or testing services. They also have direct links to universities through informal exchanges between employees or collaborative research projects (Arnold et al., 2007, pp. 105-115).

However, for those firms that participated in the 2015 wave, the data covered the period 2012–2014 because the data required to construct this variable were only available until 2014. A comparison of average and median values of *LOGFIRMSIZE* across waves showed that firm size did not change substantially over time (those statistics are not presented in this paper).

- *INDUSTRY* classified firms in five groups: "0" for other activities, "1" for non-knowledge-intensive services, "2" for low-technology manufacturing, "3" for knowledge-intensive services and "4" for high-technology manufacturing. The benchmark corresponded to firms in low-technology manufacturing. The data were obtained from IDA and covered only the last year of each wave of the Danish Research and Innovation Survey. Cross-tabulations were requested, comparing the proportion of firms that operated in each group for each wave. These proportions did not change substantially over time (those statistics are not presented in this paper). Table A2 in the Appendix shows the industry codes on which *INDUSTRY* was based.

The model is displayed below. For Hypothesis 1 to be supported, *SHAREGRAD*REGION* should be statistically significant and have a positive sign for firms in rural regions. For Hypothesis 2 to be supported, *SOURCE*REGION* and/or *COLLAB*REGION* should be statistically significant and have a positive sign for firms in rural regions. The reference category corresponds to firms in the Copenhagen metropolitan region:

$$\begin{aligned} COLLAB\_UNIi = {} & \alpha + \beta_1 REGIONi + \beta_2 SHAREGRADi \\ & + \beta_3 (SHAREGRADi * REGIONi) + \beta_4 COLLABi \\ & + \beta_5 (COLLABi * REGIONi) + \beta_6 SOURCE + \beta_7 (SOURCEi \\ & * REGIONi) + \beta_8 RDSALESi + \beta_9 LOGFIRMSIZEi \\ & + \beta_{10} PATENTSi + \beta_{11} COLLAB\_ACADEMICi \\ & + \beta_{12} SOURCE\_ACADEMICi + \beta_{13} SOURCE\_INTi \\ & + \beta_{14} DISTANCEi + \beta_{15} INDUSTRYi + \beta_{16} WAVEi + \varepsilon_{it} \end{aligned}$$

After creating correlation matrices and performing variance inflation factor (VIF) tests, no multicollinearity issues were detected, except for the correlation between *SOURCE* and *SOURCE_ACADEMIC* (r = 0.68, significant below the 1% threshold, see Table A3 in the Appendix).

3.4.5. DESCRIPTIVE STATISTICS

Table 1 shows that a roughly similar percentage of firms in rural regions collaborated with universities in innovation when compared to firms in the Copenhagen metropolitan region. This was so despite the limited university presence in rural

regions and the greater geographical distance between firms in rural regions and universities.

Table 1: Descriptives, characteristics by type of region (continues below)	**All firms (N=4772)**		**Rural regions (N=1680)**		**Intermediate regions (N=1152)**		**Copenhagen metropolitan region (N=1940)**	
Dependent variable		**Std Dev**		**Std Dev**		**Std Dev**		**Std Dev**
UNI (percent)	8.82%	28.36%	8.57%	28.01%	9.81%	29.76%	8.45%	27.83%
Explanatory variables								
SHAREGRAD (average)	14.11%	20.71%	6.85%	12.38%	13.98%	20.49%	20.46%	24.23%
SHAREGRAD (median)	4.63%	20.71%	1.84%	12.38%	4.74%	20.49%	11.18%	24.23%
Percent of firms with at least 1 graduate	65.44%	47.55%	57.32%	49.48%	67.36%	46.91%	71.34%	45.23%
COLLAB_NONACADEMIC (average)	0.72	1.41	0.73	1.44	0.71	1.36	0.72	1.43
SOURCE_NONACADEMIC (average)	3.28	1.81	3.34	1.81	3.33	1.79	3.21	1.81
Wave								
WAVE 2009-11 (number observations)	955		332		233		390	
WAVE 2010-12 (number observations)	909		336		212		361	
WAVE 2011-13 (number observations)	919		305		232		382	
WAVE 2012-14 (number observations)	931		326		215		390	
WAVE 2013-15 (number observations)	1058		381		260		417	

Table 1: Descriptives, characteristics by type of region (final)	**All firms (N= 4772)**		**Rural regions (N=1680)**		**Intermediate regions (N=1152)**		**Copenhagen metropolitan region (N=1940)**	
Control variables		**Std Dev**		**Std Dev**		**Std Dev**		**Std Dev**
DISTANCE (average time travel in minutes)	26.98	26.65	53.22	25.81	15.06	14.12	11.01	10.43
LOGFIRMSIZE (average)	3.21	1.35	3.32	1.26	3.17	1.32	3.15	1.42
SOURCE_INT (average)	1.35	0.75	1.29	0.74	1.36	0.76	1.39	0.75
SOURCE_ACADEMIC (percent)	67.67%	46.78%	69.17%	46.19%	68.49%	46.48%	65.88%	47.42%
COLLAB_ACADEMIC (percent)	9.51%	29.34%	10.89%	31.16%	9.63%	29.52%	8.24%	27.52%
RDSALES (percent)	2.47%	7.61%	1.44%	5.49%	2.59%	7.93%	3.29%	8.78%
PATENTS (percent)	8.04%	27.21%	8.09%	27.28%	8.85%	28.42%	7.53%	26.38%
INDUSTRY: Other activities (percent)	5.36%	22.53%	6.55%	24.74%	5.64%	23.08%	4.18%	20.01%
INDUSTRY: Non knowledge-intensive services (percent)	29.99%	45.83%	27.62%	44.72%	28.73%	45.27%	32.78%	46.95%
INDUSTRY: Low technology manufacturing (percent)	16.14%	36.79%	26.96%	44.39%	17.19%	37.74%	6.13%	24.01%
INDUSTRY: Knowledge-intensive services (percent)	36.29%	48.09%	21.91%	41.37%	35.51%	47.87%	49.23%	50.01%
INDUSTRY: High technology manufacturing (percent)	12.22%	32.75%	16.96%	37.54%	12.93%	33.57%	7.68%	26.63%

Looking at *DISTANCE*, as expected, firms in rural regions were by far the ones that were the farthest away from a nearest university; they had an average travel time above 53 minutes, almost five times that of their metropolitan counterparts. It should be noted, nevertheless, that 58.39% of the firms in rural regions had engaged in innovation activities, a smaller percentage than that of their metropolitan counterparts (61.95%) and that of firms in intermediate regions (62.61%). The similar percentages of firms in rural regions and in the Copenhagen metropolitan region that collaborated

with universities might also relate to the findings from Jakobsen and Lorentzen (2015), who observed that firms in rural regions were more likely to draw on external knowledge through formal channels instead of with informal exchanges. It was in intermediate regions where the largest proportion of firms collaborating with universities was found.

Regarding *SHAREGRAD*, the average share of graduates in firms in rural regions was approximately a third of that of their metropolitan counterparts and half of that of their intermediate counterparts. The differences were starker when comparing the median percentages of graduates, indicating a more skewed distribution of the presence of graduates among firms in rural regions. Also, substantial inter-regional differences were observed in the percentage of firms that employed at least one university graduate, although they did not appear to be as stark as the previous indicators. These differences in *SHAREGRAD* were expected, as one can take into account that graduate employment tends to concentrate in metropolitan regions (Florida, 2002; Gordon and McCann, 2000; McCann, 2008; Rodríguez-Pose and Fitjar, 2013; Scott, 2010; Storper and Scott, 2009).

Notable inter-regional differences were also visible in *RDSALES*, where firms in rural regions' R&D spending over sales was on average less than half that for firms in the Copenhagen metropolitan region; in *SOURCE_ACADEMIC* and *COLLAB_ACADEMIC*, where a higher percentage of firms in rural regions utilised knowledge from university sources and from sources similar to universities, compared to their metropolitan counterparts; and in *INDUSTRY*, where the highest percentage of manufacturing firms were observed in rural regions, and the highest percentage of service firms was in the Copenhagen metropolitan region.

3.5. RESULTS

3.5.1. MAIN REGRESSION ANALYSIS

Model 1 (Table 2) shows support for Hypothesis 1, stating that there was a positive association between graduate employment and the likelihood that firms collaborated in innovation with universities, and this association was stronger for firms in rural regions, compared to firms in the Copenhagen metropolitan region. This interpretation was based on the finding that *SHAREGRAD*REGION (rural)* was statistically significant below the 1% level and had a positive sign, the statistical significance and positive sign of *SHAREGRAD* and the lack of statistical significance of *REGION (rural)*.

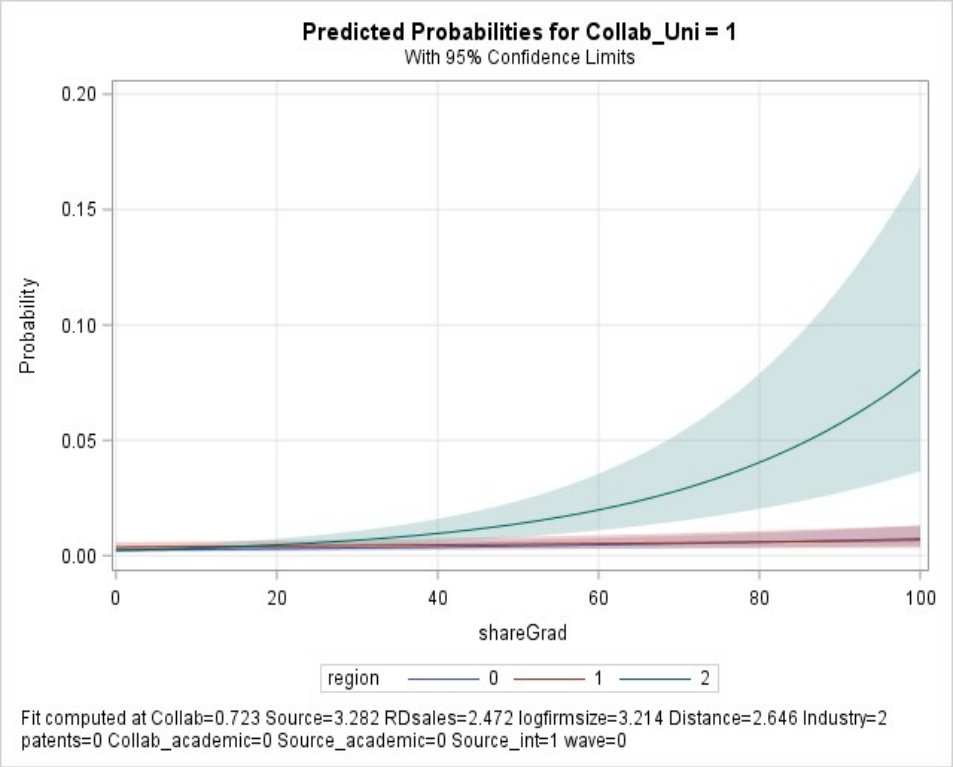
Table 2: logistic regressions, likelihood of collaborating with universities in Denmark		**Model 1**	
		Estimate	**Standard error**
Benchmark	Intercept	-6.7499***	0.3357
REGION (metro)	REGION (rural)	0.4018	0.2868
	REGION (intermediate)	1.1406***	0.2993
	SHAREGRAD	0.0112***	0.00223
SHAREGRAD*REGION (metro)	SHAREGRAD*REGION (rural)	0.0254***	0.00439
	SHAREGRAD*REGION (intermediate)	-0.0052	0.00367
	COLLAB	0.5540***	0.0383
COLLAB*REGION (metro)	COLLAB*REGION (rural)	0.0312	0.0537
	COLLAB*REGION (intermediate)	0.0348	0.0588
	SOURCE	-0.1365***	0.0519
SOURCE*REGION (metro)	SOURCE*REGION (rural)	-0.1484**	0.0671
	SOURCE*REGION (intermediate)	-0.2240***	0.0727
	RDSALES	0.0535***	0.0039
	LOGFIRMSIZE	0.2680***	0.0373
PATENTS (no)	PATENTS (yes)	1.0244***	0.1197
COLLAB_ACADEMIC (no)	COLLAB_ACADEMIC (yes)	1.8657***	0.0976
SOURCE_ACADEMIC (not important)	SOURCE_ACADEMIC (at the least a bit important)	1.8359***	0.1713
SOURCE_INT (at the least a bit important)	SOURCE_INT (not important)	0.6642***	0.1963
	SOURCE_INT (very important)	0.6930***	0.1082
	DISTANCE	-0.0871**	0.0382
INDUSTRY (low technology manufacturing)	INDUSTRY (other industries)	1.0552***	0.2222
	INDUSTRY (non knowledge-intensive services)	-0.2539*	0.1387
	INDUSTRY (knowledge-intensive services)	0.0828	0.1470
	INDUSTRY (high tech. manufacturing)	0.0409	0.1566
WAVE 2009-11	WAVE 2010-12	-0.0603	0.1303
	WAVE 2011-13	-0.4068***	0.1368
	WAVE 2012-14	0.1174	0.1301
	WAVE 2013-15	0.0952	0.1281
	N	4772	
	AIC	4461.467	
	SC	4642.642	
	-2 Log L	4405.467	
	R-Square (Max-rescaled)	0.6489	
***: significant at 10% level, **: significant at 5% level, ***: significant at 1% level**			

To provide a more meaningful measure of the extent to which graduate employment was associated with industry–university collaboration for firms in rural regions and their metropolitan counterparts, Figure 2 displays the predicted probabilities. The predicted probabilities were calculated for firms that had average values in the model's continuous variables and were in the reference category for each of the categorical variables. For firms in rural regions, higher values of *SHAREGRAD* were associated with higher probabilities of industry–university collaboration, while for firms in the Copenhagen metropolitan region, practically no change was noted in the probability of collaborating with universities. Note however that the differences between firms in the two types of regions only appeared to be statistically significant at high values of *SHAREGRAD*. The findings suggest that the relative lack of universities in rural regions might not pose much of an obstacle to firms in those regions collaborating with universities in innovation activities because graduate employees can provide a better understanding of university research and the ways universities work as organisations, facilitating cognitive proximity to the universities. In this sense, the results might reflect Boschma's (2005) suggestion that geographical proximity might be less of a necessity for collaboration to take place when there is cognitive proximity between the parties.

Whereas Model 1 provided support for Hypothesis 1, this was not the case for Hypothesis 2. *COLLAB* was statistically significant below the 1% threshold and had a positive sign, but *COLLAB*REGION (rural)* was not statistically significant, suggesting that there was a positive association between collaborating for innovation with other organisations than universities and industry-university collaboration but that this association was not stronger for firms in rural regions when compared to firms in the Copenhagen metropolitan region.

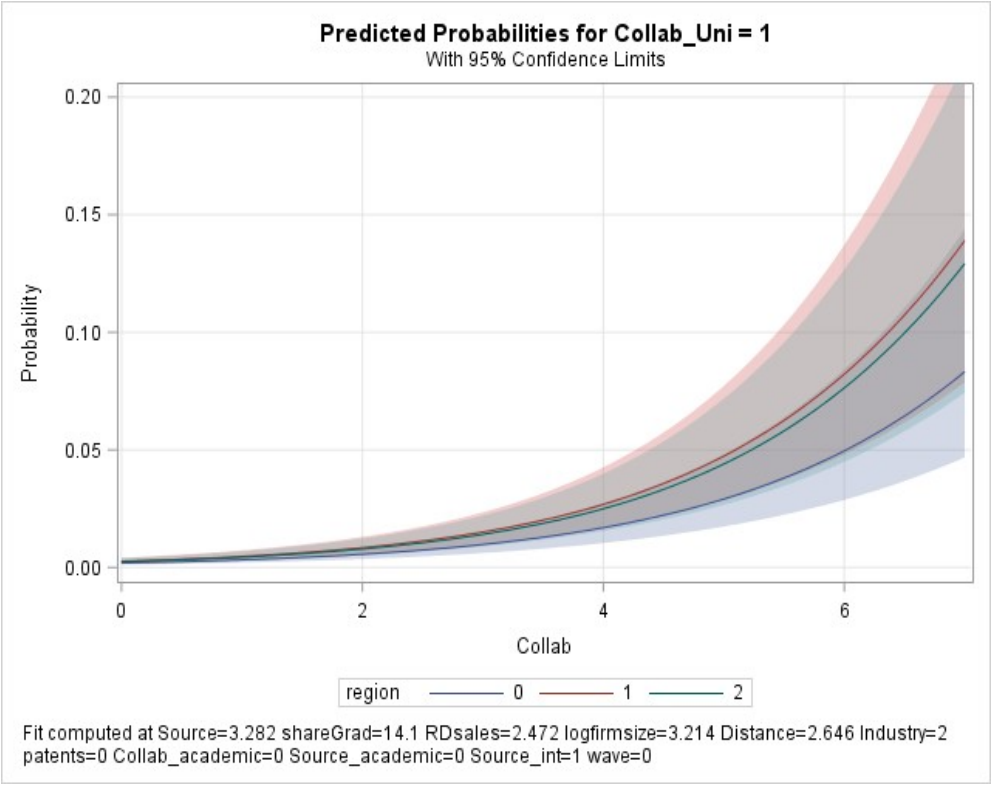
As for those forms of drawing on external non-university knowledge that do not necessarily entail collaborating with organisations, Model 1 suggests that firms in the Copenhagen metropolitan region were negatively associated with industry–university collaboration, and this association appeared to be stronger for firms in rural regions. *SOURCE* was statistically significant below the 1% threshold and had a negative sign, and *SOURCE*REGION (rural)* was statistically significant below the 1% threshold and had a negative sign. As in *SHAREGRAD*, predicted probability plots had been requested (Figures 3 and 4) suggesting a similar increase across the regions in the probability to collaborate in innovation with universities with a higher number of types of partners and a similar decrease with a higher number of types of knowledge sources, respectively.

Figure 2: Predicted probability that firms collaborate with universities at different values of *SHAREGRAD* (with 95% confidence limits)



Thus, firms that draw on external non-university knowledge firms in rural regions were not more likely to collaborate with universities than firms in the Copenhagen metropolitan region. Instead, firms that have formal collaboration channels with other organisations were more likely to collaborate with universities, independently of the type of region, and firms that drew on external knowledge sources without necessarily collaborating with them were less likely to collaborate with universities, especially firms in rural regions. Although drawing on external knowledge net of universities might contribute to a firm's ability to draw further external knowledge and achieve cognitive proximity with universities, firms in rural regions were not more likely to collaborate with universities than firms in the Copenhagen metropolitan region. Note, however, that the dataset did not allow for the assessment of whether firms drew on external knowledge inside or outside their region, and thus it is not possible to assess whether firms in rural regions were more likely to maintain extra-regional collaboration channels to offset the organisational thinness of their regions, and whether extra-regional collaborations were particularly associated with industry-university collaboration among firms in rural regions.

Figure 3: Predicted probability that firms collaborate with universities at different values of *COLLAB* (with 95% confidence limits)

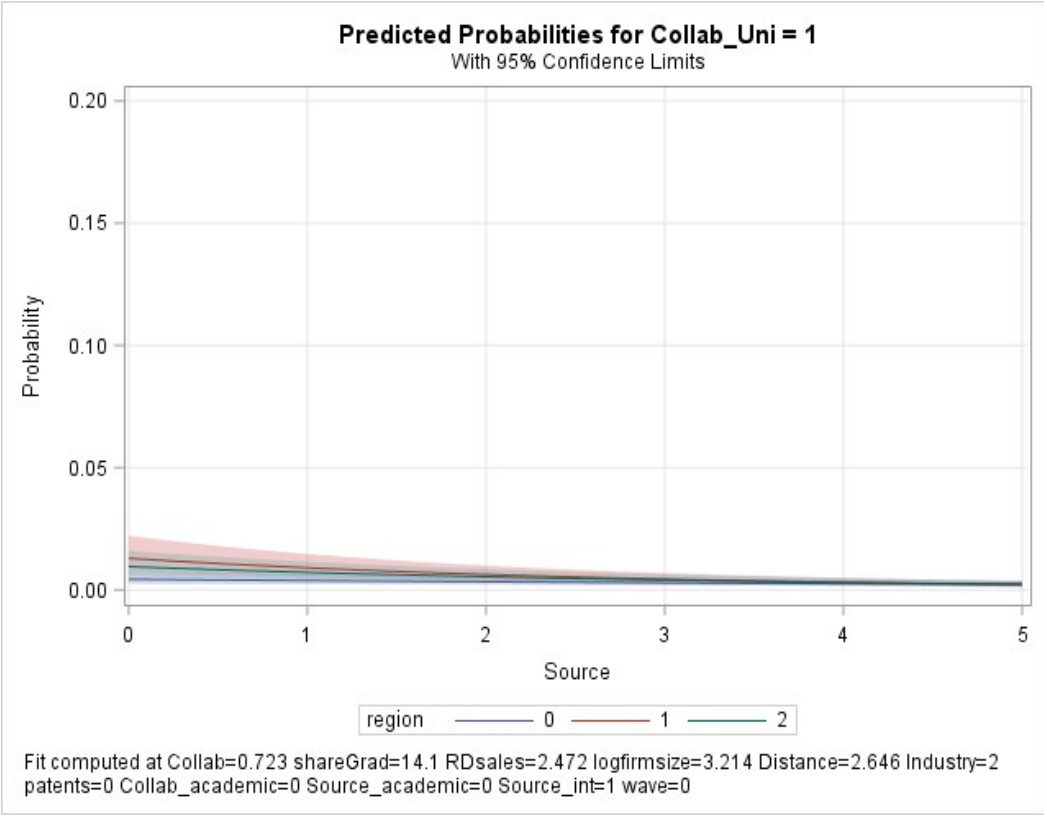


Regarding the control variables, the analysis confirmed that firms with higher levels of absorptive capacity measured by R&D intensity and patenting were more likely to collaborate with universities as expected in the industry–university collaboration literature (Laursen and Salter, 2004; Mohnen and Hoareau, 2003), since *RDSALES* and *PATENTS* had a positive sign and were statistically significant. Similarly, it was confirmed that larger firms were more likely to collaborate with universities (Laursen and Salter, 2004).

Firms were more likely to collaborate in innovation with universities if they acquired knowledge similar to that of universities, whether this entailed collaborative relationships as in *COLLAB_ACADEMIC* or not, as in *SOURCE_ACADEMIC*. The model estimated that firms that considered internal knowledge sources very important for idea development were, together with those that did not consider them important, more likely to collaborate with universities, compared to firms that considered them somewhat important. Although firms can combine internal and external knowledge as

part of their innovation activities, firms might not necessarily have to draw from internal knowledge while collaborating with universities (Criscuolo et al., 2018), and the results from Model 1 might be a reflection of this diversity in the choice of knowledge sources.

Figure 4: Predicted probability that firms collaborate with universities at different values of *SOURCE* (with 95% confidence limits)



Firms were estimated to be less likely to collaborate with universities the closer they were to the nearest university (*DISTANCE*), and this result was independent of the type of region where the firms were located. Because this variable did not provide information on the location of the focal firm's university partner, the results should be interpreted as an indication that industry-university collaboration was less likely if firms were at a relatively short geographical distance from potential university partners. As for the industry controls, firms in non-knowledge-intensive services were less likely to collaborate with universities than firms in low-technology manufacturing, and the opposite was the case for firms in other industries. Finally,

there were some yearly differences in the propensities of firms to collaborate with universities.

3.5.2. FIRMS IN RURAL REGIONS WITHIN COMMUTING DISTANCE OF A METROPOLITAN REGION

Firms in rural regions within commuting distance of a metropolitan region might have easier access to metropolitan regions and thus to universities than more peripherally located firms (Doloreux and Dionne, 2008; Shearmur and Bonnet, 2011). Thus, among firms in rural regions, those firms that were within commuting distance of a metropolitan region might present a special case with geographical proximity being more relevant in facilitating industry–university collaboration, and graduate employees' cognitive proximity to universities being less relevant. Similarly, a greater proportion of these firms might collaborate with universities without having to draw on external knowledge net of universities, since the cognitive proximity that firms obtain by drawing on external knowledge will be less necessary in order to be able to collaborate in innovation with universities.

Model 2 (Table A3 in the Appendix) explores these possibilities. Firms in rural regions located on the island of Zealand have been treated as within commuting distance of the Copenhagen metropolitan region, and firms outside the island of Zealand have been treated as beyond commuting distance (see Figure A1 in the Appendix). Due to space limitations, the analysis presented here focuses only on the explanatory variables and on the differences between the two types of firms in rural regions and their metropolitan counterparts.

Regarding Hypothesis 1 there was a statistically significant positive association between employing university graduates and collaborating in innovation with universities, because *SHAREGRAD* was statistically significant and had a positive sign. This association was stronger among firms in rural regions beyond commuting distance of the Copenhagen metropolitan region than among firms in rural regions within commuting distance, owing to the fact that *REGION (rural beyond metro commuting area)* and *SHAREGRAD*REGION (rural beyond metro commuting area)* also were statistically significant and had positive signs. In contrast, the negative sign of *REGION (rural within metro commuting area)* suggested that firms in rural regions within commuting distance of the Copenhagen metropolitan region were not necessarily more likely to collaborate with universities, even if there was more geographical proximity between these firms and universities.

Regarding Hypothesis 2, drawing on external knowledge net of universities was not associated with a higher likelihood that firms in rural regions collaborated with

universities compared to firms in the Copenhagen metropolitan region, whether the firms in rural regions were at commuting distance from Copenhagen or not.

3.5.3. ROBUSTNESS TESTS

In order to assess the robustness of the results, the following specifications of Model 1 have been explored (though not presented in this paper due to space limitations):

- In one specification, *SOURCE* and *SOURCE*REGION* were included, and *COLLAB* and *COLLAB*REGION* were excluded; in another *COLLAB* and *COLLAB*REGION* were included, whereas *SOURCE* and *SOURCE*REGION* were excluded. This however did not lead to a change in the sign and statistical significance of the remaining regression estimates. Nevertheless, the results showed that *COLLAB* and *COLLAB*REGION* increased the model's explanatory power to a greater extent than *SOURCE* and *SOURCE*REGION*, suggesting that the firms that had the capabilities to engage in collaborative relationships with other organisations were also more likely to have the capabilities to collaborate with universities (Hewitt-Dundas et al., 2019; Perkmann and Walsh, 2007).

- In another specification, *COLLAB* included all the types of organisations grouped in *COLLAB_ACADEMIC,* and *SOURCE* all the knowledge sources that could be reported by the survey participants, except for universities and scientific journals (which were included in separate control variables). The interaction between *SOURCE* and *REGION (rural)* lost statistical significance, but this had no consequences for the findings in relation to the hypotheses.

- Labour markets for university graduates are thinner in rural regions, compared to metropolitan locations (Scott, 2010; Storper and Scott, 2009). In locations where firms tend to employ relatively few university graduates like rural regions, employing one additional university graduate might increase the likelihood of collaborating with universities, whereas in locations where firms tend to employ a relatively large number of university graduates, like the Copenhagen metropolitan region, employing more university graduates might not measurably increase the chances of collaborating with universities. To test for this possibility, an additional model included the quadratic term *SHAREGRAD*SHAREGRAD* in addition to *SHAREGRAD*. A positive, statistically significant interaction between *SHAREGRAD*SHAREGRAD* and *REGION* for firms in rural regions would point to decreasing returns to the likelihood of collaborating with universities among firms in the Copenhagen metropolitan region. However, the

interaction term of *SHAREGRAD*SHAREGRAD* and *REGION (rural)* had a negative sign, suggesting that firms in the Copenhagen metropolitan region employing additional university graduates were associated with increasing returns to the likelihood of collaborating with universities.

- Excluding from Model 1 those firms that participated in the 2015 wave did not affect the results.

- Finally, the results from Model 1 did not change if interaction terms of *INDUSTRY* and *REGION* were included.

3.6. DISCUSSION AND CONCLUSION

The findings of this paper contribute to the exploration of how industry–university collaboration in innovation takes place in different types of regions. In doing so, they add to a literature that until recently mostly focused on factors associated to industry-university collaboration independent of regional location (D'Este et al., 2013; D'Este and Iammarino, 2010; Johnston and Huggins, 2016). Firms in rural regions that employed university graduates were more likely to collaborate with universities than similar firms in the Copenhagen metropolitan region. Among firms in rural regions, not having universities in their regions might not be so much of an obstacle to industry–university collaboration if these firms rely on the cognitive proximity to universities that graduate employees can provide. University graduates might not just contribute to their firms' absorptive capacity but might also provide knowledge of the research conducted at universities and how universities operate as organisations.

Previous research has already pointed out that the association between geographical proximity and industry–university collaboration might be explained by graduate employees' cognitive proximity to university research and social proximity to staff from universities (Breschi and Lissoni, 2001; Drejer and Østergaard, 2017; Østergaard, 2009). This paper provides a deeper understanding of the role of cognitive proximity for industry–university collaboration in rural and metropolitan regions. There is also the possibility that graduate employees' social ties to staff at their *alma mater* institutions are particularly relevant to linkages between firms in rural regions and universities; however, *SHAREGRAD* did not allow the assessment of whether this was the case. In order to do so, future research could follow an approach similar to that of Drejer and Østergaard (2017), running separate regressions on the likelihood that firms collaborate with each of the Danish universities and replacing *SHAREGRAD* with an explanatory variable that measures the share of employees educated at each focal university. Compared to *SHAREGRAD*, this variable should be better able to capture any association related to the social proximity between firms and the focal university. If firms in rural regions that employ graduates from a specific

university are more likely to collaborate with it, this might be because these graduates have social ties with staff at the university. A second explanatory variable could measure the share of employees educated at other universities than the focal one. Because these employees would not have received training at the focal university, this variable would capture whether these employees contribute to the firm's ability to integrate university knowledge, that is the cognitive proximity to universities. Nevertheless, this approach would not be without challenges. For example, because there would be fewer observations with positive values in the dependent and explanatory variables, it is less likely that the models could detect any relations between them.

An alternative approach to the challenge of discerning whether and how graduate employment can be relevant to cognitive and social proximity between firms in rural regions and universities might entail complementing quantitative research like the present one with case studies. Because the present paper cannot propose causal relationships owing to its cross-sectional nature, a case study would allow exploration as to whether and how graduate employees' social ties to university staff might contribute to social proximity between a firm and the universities where these employees obtained their degrees. Case studies would also enable the further exploration of how graduate employees might be more conducive to the formation of cognitive proximity between their firms and university research and would be useful in providing theoretical explanations for why firms in rural regions beyond the commuting area of the Copenhagen region were actually more likely to collaborate with universities than their metropolitan counterparts, even when comparing firms that *did not employ* university graduates (Model 2). For now, a potential explanation might be that firms in this type of rural region were more likely to collaborate for innovation, because unplanned, informal exchanges were insufficient to acquire the knowledge they needed as part of their innovative processes (Jakobsen and Lorentzen, 2015).

In line with previous research (Drejer and Østergaard, 2017; Hewitt-Dundas et al., 2019; Laursen and Salter, 2004), this paper confirmed that firms might collaborate with organisations other than universities as part of their knowledge acquisition strategies and that drawing on external knowledge net of universities might help them decrease the cognitive distance with universities—and decrease the importance of geographical proximity—by increasing the knowledge-sourcing capabilities of firms. Taking into account that firms in rural regions are farther away from universities than their metropolitan counterparts, drawing on external non-university knowledge was expected to be particularly supportive to industry-university collaboration among firms in rural regions; however, this did not seem to be the case. Drawing on external knowledge net of universities by collaborating with different types of organisations (Drejer and Østergaard, 2017; Hewitt-Dundas et al., 2019) was positively associated with industry–university collaboration, whereas this association was negative when it came to draw on external non-university knowledge without necessarily collaborating

with other organisations. Note however that the dataset did not allow for the differentiation of whether firms' knowledge acquisition strategies involved links with extra-regional organisations and that previous research has pointed out that firms in relatively isolated locations are more likely to collaborate for innovation with extra-regional partners than firms in metropolitan regions (Grillitsch and Nilsson, 2015). Hence, the present results might benefit from complementary research with datasets that allow for the identification of whether the focal firm's external partners are within or outside the firm's region. In that way, it would be possible to further assess whether drawing external non-university knowledge through extra-regional partners was more conducive to industry-university collaboration among firms in rural regions. Furthermore, in that way, it would also be easier to propose theoretical explanations for why drawing on external knowledge net of universities was similarly associated to industry-university collaboration among firms in rural regions and in the Copenhagen metropolitan region.

While the present paper would benefit from further research discerning theoretical explanations for its findings, cross-country research could extend its generalisability. This was a single-country study and a firm's perception of geographical distance with universities might differ in larger, more sparsely populated Nordic countries such as Sweden, Norway and Finland. Furthermore, Copenhagen is the only metropolitan region in the country, and its nature as a political capital might also influence the results. These limitations provide additional opportunities for research. Cross-country research involving larger, more sparsely populated countries, as well as countries with more metropolitan regions than just the nation's capital, could contribute to determining whether the associations observed in the present study hold in other contexts.

The results suggest interesting implications for the design of industry–university collaboration policies and further legitimise the university's mission as a provider of highly skilled employees to regional firms and as a promoter of firm innovation and regional development (Charles, 2006; Evers, 2019; Nilsson, 2006). Policies that promote firms in rural regions drawing on external non-university knowledge might also contribute to the cognitive proximity of firms to universities, helping to further connect firms in rural regions and universities, but the results indicate that these policies might be similarly effective for firms in the Copenhagen metropolitan region. In addition, initiatives that support graduate employment in rural regions might not only contribute to the absorptive capacity of these firms (Drejer and Østergaard, 2017) but might also be particularly supportive to incentivise links between these firms and universities. An example of these policies could be the introduction by the Danish government in 2016 of a two-year subsidy to firms in rural areas that employ highly skilled professionals for innovation projects (Knudsen et al., 2018, p. 17).

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Disclosure statement

Declarations of interest: none.

Appendix

Table A1: List of Municipalities per Functional Urban Area	
Copenhagen Metropolitan Area	Albertslund, Allerød, Ballerup, Brøndby, Copenhagen, Dragør, Egedal, Fredensborg, Frederiksberg, Frederikssund, Furesø, Gentofte, Gladsaxe, Glostrup, Greve, Helsingør, Herlev, Hillerød, Hvidovre, Høje-Taastrup, Hørsholm, Ishøj, Køge, Lejre, Lyngby-Taarbæk, Roskilde, Rudersdal, Rødovre, Solrød, Tårnby, Vallensbæk
Aarhus	Aarhus, Favrskov, Odder, Skanderborg, Syddjurs
Odense	Assens, Faaborg-Midtfyn, Kerteminde, Nordfyns, Nyborg, Odense
Aalborg	Aalborg, Brønderslev, Jammerbugt, Rebild
Esbjerg	Esbjerg, Fanø, Varde

Source: OECD, n.d.

Table A2: Industry Classifications (continues below)

Industry Variable	Industry Aggregations	NACE Rev.2 Branch Codes
Other activities	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.
	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.
	Construction	(41) Construction of buildings; (42) civil engineering; (43) specialised construction activities.
Low technology manufacturing	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.
	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.
High technology manufacturing	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.
	High technology manufacturing	(21) Manufacture of basic pharmaceutical products and pharmaceutical preparations; (26) manufacture of computer, electronic and optical products.

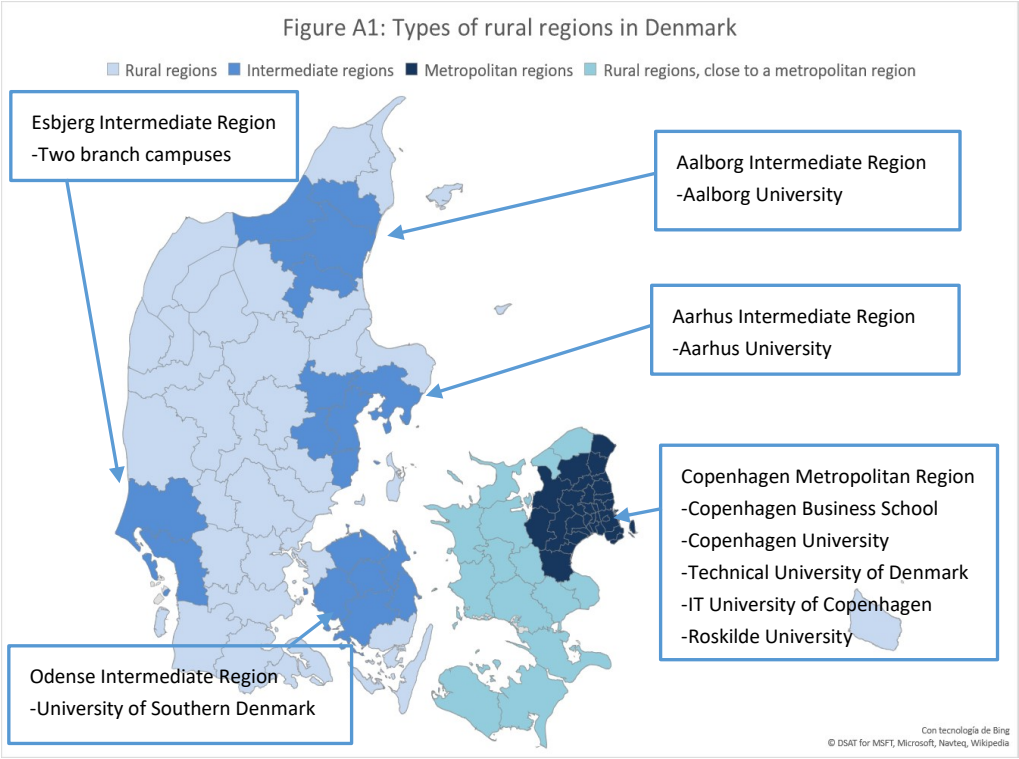
Table A2: Industry Classification (final)		
Industry Variable	**Industry Aggregations**	**NACE Rev.2 Branch Codes**
Knowledge-intensive services	Knowledge-intensive services	(50) Water transport; (51) air transport; (58) publishing activities; (59) motion picture, video and television programme production, 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.
Non-knowledge-intensive services	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.

Table A3: Correlation Matrix of Explanatory and Control Variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
1. DISTANCE	1	0.19***	0.03**	0.01	-0.16***	0.09***	0.08***	0.03***	0.01***	-0.02***	0.09***	0.17***	0.52***
2. SHAREGRAD		1	0.12***	0.05***	-0.13***	0.21***	0.13***	0.03**	0.07***	0.03**	0.25***	0.11***	0.26***
3. COLLAB			1	0.19***	0.06***	0.18***	0.23***	0.49***	0.17***	0.15***	0.07***	-0.01	-0.01
4. SOURCE				1	0.07***	0.07***	0.52***	0.12***	0.68***	0.08***	0.08***	0.01	0.04**
5. LOGFIRMSIZE					1	-0.13***	0.15***	0.09***	0.01	0.12***	-0.25***	-0.04***	-0.09***
6. RDSALES						1	0.15***	0.11***	0.08***	0.09***	0.19***	0.01	0.09***
7. SOURCE_INT							1	0.42***	0.56***	0.36***	0.16***	0.01	0.08***
8. COLLAB_ACADEMIC								1	0.58***	0.52***	0.15***	0.09***	-0.08***
9. SOURCE_ACADEMIC									1	0.35***	0.13***	0.04*	-0.05**
10. PATENTS										1	0.29***	0.03	-0.02
11. INDUSTRY											1	0.01	0.02
12. WAVE												1	-0.01
13. REGION													1

*: significant at 10% level, **: significant at 5% level, ***: significant at 1% level

Table A4: Logistic Regression, Likelihood of Collaborating with Universities in Denmark. REGION (metro) as Benchmark		**Model 2**	
		Estimate	Standard error
Benchmark	Intercept	-6.7506***	0.3367
REGION (metro)	REGION (rural beyond metro commuting area)	0.7307**	0.2920
	REGION (rural within metro commuting area)	-2.2276***	0.8107
	REGION (intermediate)	1.1513***	0.3008
	SHAREGRAD	0.0112***	0.00223
SHAREGRAD*REGION (metro)	SHAREGRAD*REGION (rural beyond metro commuting area)	0.0233***	0.00479
	SHAREGRAD*REGION (rural within metro commuting area)	0.0477***	0.0112
	SHAREGRAD*REGION (intermediate)	-0.00519	0.00368
	COLLAB	0.5525***	0.0383
COLLAB*REGION (metro)	COLLAB*REGION (rural beyond metro commuting area)	0.0565	0.0569
	COLLAB*REGION (rural within metro commuting area)	0.0221	0.1102
	COLLAB*REGION (intermediate)	0.0338	0.0588
	SOURCE	-0.1407***	0.0520
SOURCE*REGION (metro)	SOURCE*REGION (rural beyond metro commuting area)	-0.2031***	0.0701
	SOURCE*REGION (rural within metro commuting area)	0.2583	0.1676
	SOURCE*REGION (intermediate)	-0.2266***	0.0729
	RDSALES	0.0535***	0.00387
	LOGFIRMSIZE	0.2627***	0.0375
PATENTS (no)	PATENTS (yes)	1.0170***	0.1201
COLLAB_ACADEMIC (no)	COLLAB_ACADEMIC (yes)	1.8754***	0.0984
SOURCE_ACADEMIC (not important)	SOURCE_ACADEMIC (at the least a bit important)	1.8422***	0.1708
SOURCE_INT (at the least a bit important)	SOURCE_INT (not important)	0.6007***	0.1988
	SOURCE_INT (very important)	0.7112***	0.1091
	DISTANCE	-0.0935**	0.0381
INDUSTRY (low technology manufacturing)	INDUSTRY (other industries)	1.0786***	0.2248
	INDUSTRY (non-knowledge-intensive services)	-0.1819	0.1405
	INDUSTRY (knowledge-intensive services)	0.1069	0.1485
	INDUSTRY (high technology manufacturing)	0.0508	0.1578
WAVE 2009-11	WAVE 2010-12	-0.0512	0.1305
	WAVE 2011-13	-0.3841***	0.1370
	WAVE 2012-14	0.1036	0.1306
	WAVE 2013-15	0.1186	0.1287
	N	4772	
	AIC	4412.409	
	SC	4619.466	
	-2 Log L	4348.409	
	R-Square (Max-rescaled)	0.6538	
*: significant at 10% level, **: significant at 5% level, ***: significant at 1% level			



Sources: Danish Ministry of Higher Education and Science, n.d.; OECD, 2012, n.d.

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CHAPTER 4. PAPER C. BRIDGING THE GAP BETWEEN FIRMS AND UNIVERSITIES: FIRM LINKS WITH RESEARCH AND TECHNOLOGY ORGANISATIONS IN DIFFERENT TYPES OF REGIONS

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4.1. ABSTRACT

This study examined how collaboration with research and technology organisations (RTOs) was associated with industry-university collaboration as part of firms' innovative activities in different types of geographical regions. By combining data from the Danish Research and Innovation Survey and Danish register data at different points in time, the link between firms' collaboration with RTOs and their collaboration with universities in Denmark was studied. Also, the link between the firms' locations in peripheral regions, non-metropolitan university regions or the metropolitan region of Copenhagen and their collaboration with universities in Denmark were also studied. The results suggest that firms that collaborate with RTOs are more likely to collaborate with universities. This paper argues that collaboration with RTOs is associated with a higher likelihood of industry-university collaboration because this experience of collaboration allows firms to overcome barriers for collaboration with universities, which are related to differences in norms and incentive systems between firms and universities. When looking at different types of regions, firms in peripheral and metropolitan regions that collaborated with RTOs were more likely to collaborate with universities. However, firms in non-metropolitan university regions that collaborated with RTOs were not more likely to collaborate with universities.

4.2. INTRODUCTION

Differences in norms and incentive systems between firms and universities pose a difficulty in the establishment of industry-university collaboration (Bruneel, D'Este, & Salter, 2010). However, it has been shown that firms are more likely to interact with universities if they interact with organisations other than universities (Laursen, Reichstein, & Salter, 2011; Laursen & Salter, 2004). With few recent exceptions (Hewitt-Dundas, Gkypali, & Roper, 2019), the exact types of organisations that are associated with industry-university collaboration on innovation are not so well known. This study aimed at providing insights on the types of organisations that are related with industry-university collaboration by assessing whether industry-university collaboration on innovation was more likely if firms collaborated with research and technology organisations (RTOs) by answering the following research question:

"Is collaboration with RTOs on innovation positively associated with industry-university collaboration on innovation?"

RTOs are organisations whose functions focus on providing technical services to their client firms and rapidly applicable solutions to problems faced by these firms in their innovative activities. Their functions also include technology diffusion among client firms and applied research (Giannopoulou, Barlatier, & Pénin, 2019). Previous reports

suggest that the functions of universities and RTOs are complementary, with universities being more focused on basic research and RTOs on consultancy and testing services (Arnold et al., 2007; Arnold, Clark, & Jávorka, 2010).

The paper also aims at assessing whether the association between firm collaboration with RTOs and firm collaboration with universities might differ in different types of regions. Policymakers have seen in universities an institution that can support innovation and regional development (Breznitz & Feldman, 2012; Charles, 2006; Uyarra, 2010). However, regions differ in their organisational diversity and in their capacity to innovate (Tödtling & Trippl, 2005; Trippl, Asheim, & Miörner, 2015). Peripheral regions are less likely to host universities than metropolitan regions (Charles, 2016; Eder, 2019; Tödtling & Trippl, 2005; Trippl et al., 2015). They are also more likely to host firms operating in sectors traditionally not likely to draw on university research as part of their innovative activities (Isaksen & Karlsen, 2013; Tödtling & Trippl, 2015). Nevertheless, evidence from Scandinavian countries shows that a higher percentage of firms in peripheral regions collaborate with universities compared to their metropolitan counterparts (Guerrero, 2020; Jakobsen & Lorentzen, 2015). Firms in peripheral regions need to overcome longer distances than their metropolitan counterparts in order to collaborate with universities (Johnston & Huggins, 2016). An improved understanding of the factors associated with industry-university collaboration in different types of regions might help policymakers fine tune universities' regional mission to the characteristics of the regions where they are located. Thus, this study tried to answer a second research question:

"Does the association between collaboration with RTOs and industry-university collaboration on innovation vary depending on the type of region where firms are located?"

This paper combines data from the Danish Research and Innovation Survey, which is the Danish version of the Community Innovation Survey; and the Danish Integrated Labour Market database (IDA, in Danish), a register dataset managed by Statistics Denmark (see section 4.4). It is a cross-sectional dataset created with firms that participated in one or more waves of the Danish Research and Innovation Survey between 2010 and 2014. Because this is a cross-sectional dataset, the analyses only aim at identifying statistical associations, not causal mechanisms.

Logistic regressions were run on the likelihood that firms collaborated on innovation with universities in Denmark as part of their innovative activities and depending on whether firms collaborated with RTOs. Secondly, these regression analyses explored whether the association between firm collaboration with RTOs and firm collaboration with universities differed across different types of regions. The results showed that if firms were collaborating with RTOs, they were more likely to be collaborating with universities. However, the results also showed that this association was only valid for firms in peripheral and metropolitan regions. Among the firms that did not collaborate

with RTOs, those that were in peripheral regions and non-metropolitan university regions were more likely to collaborate with universities.

A possible explanation of the findings is that firms through collaborating with RTOs become better equipped to collaborate with Danish universities. Concerning the regional differences, collaboration with RTOs is only positively associated with university collaboration in peripheral and metropolitan regions; this might be due to universities in non-metropolitan university regions being more committed to developing collaborative relationships with regional firms (Boucher et al., 2003). This regional commitment of universities could reduce the need for RTOs as intermediaries or bridges that can help overcome the distances between universities and firms. Further research is needed to assess whether the statistical associations found in the study are driven by these mechanisms.

4.3. LITERATURE REVIEW

4.3.1. OVERCOMING BARRIERS FOR COLLABORATION BETWEEN FIRMS AND UNIVERSITIES

Firms must overcome several obstacles to incorporate industry-university collaboration into their innovation activities. High absorptive capacity, or the ability to acquire, assimilate and integrate external knowledge into organisational routines (Cohen & Levinthal, 1990), has been found to facilitate interaction with universities (Drejer & Østergaard, 2017; Laursen & Salter, 2004; Mohnen & Hoareau, 2003). Larger firms are more likely to interact with academic institutions because they have the resources needed to exploit university knowledge (Laursen & Salter, 2004; Mohnen & Hoareau, 2003). Science-based industries are also more inclined to draw on university knowledge (Pavitt, 1984; Segarra-Blasco & Arauzo-Carod, 2008). Also, firms that draw knowledge from a wide range of external sources are more likely to collaborate with universities (Hewitt-Dundas et al., 2019; Laursen & Salter, 2004).

Bruneel et al. (2010) and Hewitt-Dundas et al. (2019) point out that a range of orientation-related barriers can potentially prevent collaboration between firms and universities; firms might expect to appropriate and exploit the benefits of discoveries through secrecy, while academic researchers might expect to be able to disseminate the research they generate. The timing of academic research might also be an issue for firm partners, with the latter expecting research that should be rapidly applicable. In addition, there might be a mutual lack of understanding between both parties regarding work practices. Transaction-related barriers might also pose a challenge to industry-university collaboration, with potential conflicts between universities and their firm partners regarding the ownership of intellectual property. However, these barriers can be lowered if firms and universities can develop routines that facilitate

industry-university collaboration through previous experiences of industry-university collaboration. Thus, the findings of Bruneel et al. (2010) and Hewitt-Dundas et al. (2019) suggest that barriers deterring industry-university collaboration can be overcome through specific experiences of it.

Previous research points to other ways of lowering the barriers between firms and universities than those that stem from previous experiences of industry-collaboration. Rosenkopf and Nerkar (2001) and Rothaermel and Alexandre (2009) observe that firms that combine knowledge from internal and external sources are better able to innovate because the combination of internal and external knowledge allows them to stay abreast of technological changes. Laursen et al. (2004) and Laursen and Salter (2011) found that firms that interacted with a wide range of different types of organisations were more likely to interact with universities. Hewitt-Dundas et al. (2019) found that previous collaboration with customers was positively associated with industry-university collaboration among small and medium-sized enterprises (SMEs), whereas among larger firms previous collaboration with consultants was positively associated with industry-university collaboration.

According to Hewitt-Dundas et al. (ibid)**,** firms might be better equipped to search and identify knowledge from universities if they collaborate with specific types of organisations other than universities. The experience of collaborating with these organisations, they argue, enables firms to be better equipped to deal with differences in norms and incentive systems with non-university organisations, but also with universities. Firms should, in turn, be better equipped to identify useful knowledge from, and collaborate with other organisations, including universities. Knowledge intermediaries might be one of the types of organisations that are associated with firms being better equipped to collaborate with universities. Knowledge intermediaries are described as organisations whose functions do not limit themselves to 'translate' the knowledge generated in other organisations in such a way that the client firm can integrate it but can include technology forecasting, the combination of knowledge from different sources, and matchmaking between different parties (Bessant & Rush, 1995; Giannopoulou et al., 2019; Howells, 2006). Indeed, these organisations have been found to help firms in being better equipped to collaborate with other firms and other types of organisations in innovation networks, thus, overcoming collaboration barriers (Aquilani, Abbate, & Codini, 2017; Hermann, Mosgaard, & Kerndrup, 2016; Nauwelaers, 2011; Parker & Hine, 2014).

Because of their functions, some kinds of knowledge intermediaries, like RTOs, might be more strongly associated with industry-university collaboration than others. Arnold et al. (2007, 2010) and Giannopoulou et al. (2019) describe RTOs as organisations that, similar to higher education institutions, receive public funding to conduct research, involving in some cases peer-reviewed publications. However, unlike higher education institutions, RTOs tend to have a more short-term firm-service orientation, offering testing and consultancy services to their customers in addition to

collaborative research. These researchers suggest that links between RTOs and universities are common, whether through informal contacts or formalised collaborative research.

Hence, the norms and incentive systems regulating the functioning of RTOs can be seen as partly overlapping with those of universities but also with those of firms. RTOs might help to bridge the distance between firms and universities directly because RTOs work together with firms and universities in joint collaborative research projects. Through their social ties with university researchers, researchers at RTOs might also link firms and universities. Indirectly, firms that collaborate with RTOs might also acquire experience on how to collaborate with an organisation whose norms and incentive systems are not far from those of universities, eventually applying this experience in collaborations with universities. Either way, the first hypothesis suggests that collaboration between firms and RTOs is positively associated with collaboration between firms and universities:

H1: Firms that collaborate with RTOs are more likely to collaborate with universities when compared to firms that do not collaborate with RTOs.

These arguments do not imply that firms are the only party that has to be better equipped to collaborate. Indeed, RTOs might be able to connect university researchers with firms in collaborative research projects. By collaborating with RTOs, university researchers might be better equipped to collaborate with an organisation whose norms and incentive systems are not distant from those of their institutions, eventually applying this experience in collaborations with firms. However, the focus of this study is on the association between firms' collaboration with RTOs and firms' collaboration with universities.

4.3.2. THE ASSOCIATION BETWEEN COLLABORATION WITH RTOS AND COLLABORATION WITH UNIVERSITIES IN DIFFERENT TYPES OF REGIONS

Peripheral regions are relatively sparsely populated locations with few or no urban agglomerations. Compared to more densely populated locations, these regions tend to host a narrow variety of organisations, whether these are part of the regional innovation system's knowledge generation and diffusion subsystem, such as RTOs or public research institutes, or the knowledge application and exploitation subsystem, such as customers, suppliers and competitors (Guerrero, 2020; Tödtling & Trippl, 2005, 2015; Zukauskaite, Trippl, & Plechero, 2017). They also tend to host firms operating in sectors traditionally not likely to draw on university research as part of their innovative activities (Isaksen & Karlsen, 2013; Tödtling & Trippl, 2015). In addition to these characteristics, peripheral regions tend to be relatively far from large

urban agglomerations and the communication infrastructures that these agglomerations contain, such as ports and airports (Doloreux & Dionne, 2008; Shearmur & Doloreux, 2018). According to a recent literature review (Eder, 2019), the *peripheriality* of these regions is both geographic, because these are relatively isolated locations, compared to more densely populated ones, and economic, because of the relatively low density of economic agents in these regions. This economic *peripheriality* is also visible when it comes to the presence of universities, as one of the organisations that are part of the regional innovation system's knowledge generation and diffusion subsystem. Charles (2016) shows that peripheral regions might contain branch campuses, perhaps established for regional development purposes, but these academic institutions are likely to be smaller and have less research capacity than main university campuses, and thereby their capacity to operate as innovation partners is relatively limited.

Metropolitan regions present the opposite picture with large urban agglomerations and a broad variety of organisations in the knowledge generation and diffusion subsystem, including multiple universities (Guerrero, 2020; Tödtling & Trippl, 2015; Trippl et al., 2015). Metropolitan regions also host a broad variety of organisations in the knowledge application and exploitation subsystem, including firms in sectors traditionally linked to university research (Storper, 2018). In addition, these regions are typically well endowed with major communication infrastructures such as ports and airports, ensuring their connectedness to global knowledge networks (McCann, 2008; Rodríguez-Pose & Fitjar, 2013).

Eder (2019) and Nilsson (2006) show that there are regions, in between peripheral and metropolitan regions, that tend to have an urban agglomeration with a university campus. These regions, referred to in this paper as *non-metropolitan university regions*, can also be home to both firms traditionally not linked to universities and firms reliant on university research. Eder (ibid) adds that the university region's main urban agglomeration is also likely to contain major transport infrastructures, ensuring the region's connectedness to global knowledge networks; also, Eder (ibid) points out that the *peripheriality* of these regions is mainly economic, because of the relatively low density of economic agents that these regions contain, compared to more densely populated locations. Thus, non-metropolitan university regions host a variety of organisations that are in-between that of peripheral and metropolitan regions, whether they are part of the regional innovation system's knowledge generation and diffusion subsystem or the knowledge exploitation subsystem.

Section 4.3.1 argued that firms that interact with organisations with different norms and incentive systems are better equipped to collaborate with universities. In regions with a broad variety of organisations, firms should be better equipped to collaborate with universities by drawing on informal, unplanned exchanges from regional organisations. Hence, in metropolitan regions, unplanned exchanges with regional organisations might help firms be better equipped to collaborate with universities.

Unplanned encounters between firms' personnel and that of other regional organisations might put firms in touch with a wide range of organisations. Firms in metropolitan regions can, in turn, be better equipped to collaborate with organisations that operate under other norms and incentive systems, such as universities. Collaboration arrangements with RTOs might also help firms be better equipped to collaborate with universities; however, unplanned encounters with other regional organisations might already suffice to equip firms for collaboration with universities.

At the other extreme, the small variety of organisations in peripheral regions might not help firms be better equipped to collaborate with organisations with different norms and incentive systems, such as universities, if firms rely on informal, unplanned exchanges with staff from other organisations in the region. However, collaboration with RTOs might provide the experience that firms in peripheral regions need to be better equipped to collaborate with universities. Firms in peripheral regions might be able to draw from experience in collaboration channels with RTOs and find it useful for collaborating with universities. Furthermore, RTOs can also put peripheral regions' firms in touch with universities, for example, through collaborative research. Either way, firms in peripheral regions might be more inclined to collaborate with universities than firms in metropolitan regions if they have collaborated with RTOs.

H2: Firms in peripheral regions that collaborate with RTOs are more likely to collaborate with universities when compared to similar firms in metropolitan regions.

Compared to the other types of regions, non-metropolitan university regions present a special situation. The variety of organisations they host should be roughly in-between that of peripheral and metropolitan regions, and unplanned interactions might provide firms with less experience on how to overcome differences in norms and incentive systems with universities compared to firms in metropolitan regions. In this view, collaboration with RTOs for firms in non-metropolitan regions might be (compared to those in metropolitan regions) more positively associated with collaboration with universities, because they might acquire through the RTOs the capabilities that help them be better equipped to collaborate with universities. On the other hand, in non-metropolitan university regions, unplanned interactions might suffice for firms to be equipped to collaborate with universities. In this view, firms in university regions that collaborate with RTOs might not be more likely to collaborate with universities, compared to similar firms in metropolitan regions. Hence, there are no clear grounds to hypothesise whether firms in university regions that collaborate with RTOs are more likely to collaborate with universities, compared to similar firms in metropolitan regions.

4.4. RESEARCH METHODS

4.4.1. DATA SOURCES

In this study, data were combined from two datasets managed by Statistics Denmark, the Integrated Database for Labour Market Research (IDA, in Danish) and the Danish Research and Innovation Survey, which is the Danish version of the Community Innovation Survey. The IDA database is a register dataset that combines personal-level data on the Danish population with workplace-level data on the population of firm workplaces in Denmark (Timmermans, 2010). The Danish Research and Innovation Survey is conducted every year by Statistics Denmark and provides data on such indicators as the types of innovation developed by firms, the types of organisations that firms cooperate with as part of their innovative activities and the geographical location of these partners (Eurostat, n.d.; Laursen & Salter, 2004; Statistics Denmark, 2015). Only firms that reported the conduct of innovative activities[26] were included in the analysis, due to the focus of the study on collaboration on innovation and because the Danish Research and Innovation Survey itself only enquires of firms that reported on activities about collaboration on innovation. When constructing the dataset, the approach followed was the same as that was followed in previous work on industry-university collaboration in different types of regions in Denmark by the author (Guerrero, 2020).

The percentage of firms that collaborated with Danish universities as part of their innovative activities has fluctuated between 2010 and 2014, with a tendency for higher collaboration percentages in even years and lower percentages in odd years, for example, shifting from 9% in 2013 to 12% in 2014 (Erhvervsstyrelsen, n.d.). A likely cause for this variation is the design of the Danish Research and Innovation Survey questionnaires. During odd years, the questionnaires include more questions about research and development (R&D) activity, and a lower number of firms appear to report collaboration with universities as a likely result of respondent fatigue[27]. Taking into account that firms' propensity to report collaboration on innovation can vary from year to year, a pooled cross-section was constructed, merging all the observations from three samples of the Danish Research and Innovation Survey (the 2012 wave,

[26] These are the introduction of new or significantly improved products, manufacturing processes, operations, organizational structures or marketing techniques, as well as ongoing or abandoned innovation activities during the survey period.

[27] This pattern was reproduced in practically all the years in the time series reported by Erhvervsstyrelsen (n.d.). The only exception appeared to be in the shift between 2012 and 2013, since the percentage of firms that reported collaboration with universities was the same between the two years, probably because of the crisis that affected Denmark in those years.

where managers were asked for innovative activities between 2010 and 2012; the 2013 wave, covering 2011–2013; and the 2014 wave, covering 2012–2014[28]).

The surveys are compulsory, minimising the number of non-responses. Each wave included all the firms in the population with more than 100 full-time equivalent employees (FTEs). The lower the number of FTEs, the lower the likelihood of being selected for a wave (Statistics Denmark, 2012, 2015). Hence, in the pooled data set, all firms with more than 100 FTE would appear three times—one for each wave included—whereas there was a lower likelihood that firms with less than 100 FTEs would appear in two consecutive waves of the survey. The weights provided by Statistics Denmark are used to adjust the observations by firm size and the firm's activity branch in order to ensure that each wave is representative of the firm population in Denmark. However, because the pooled sample included more than one observation for those firms that participated in more than one wave, the weights provided by Statistics Denmark have been modified in the present study, dividing them by the number of waves in which the focal firm had participated in the survey. That is, for a firm that had participated in three waves, the weights provided by Statistics Denmark were divided by three; for a firm that had participated in two waves, the weights were divided by two; and for firm that had participated in one wave the weights were not divided.

This approach provided a number of observations large enough to study phenomena as infrequent as industry-university collaboration on innovation. In the pooled cross-section, 7.3% of the firms collaborated with Danish universities, and only a fraction of them collaborated with RTOs (see table 2, below)[29]. A crucial limitation in this approach, however, was that it did not allow for the study of causal relationships since the explanatory and dependent variables corresponded to the same wave of the Danish Research and Innovation Survey.

The Danish Research and Innovation Survey included 4901 observations in the 2014 wave, 4788 in the 2013 wave and 4698 in the 2012 wave. After deleting observations with missing or extreme values in the control variables, the merged sample had 10610 unweighted observations. Once those observations that did not develop innovative

[28] Statistics Denmark derives its statistical population from the Business Statistical Register, defining a frame of enterprises and deleting certain activities and firms with few employees. Statistics Denmark also weights the final frame population (Statistics Denmark, 2015).

[29] Furthermore, a balanced panel dataset with firms that had participated in consecutive waves would have a number of observations substantially smaller than the one obtained through a pooled cross-section (see below), because only large firms were likely to participate in consecutive waves. For instance, a panel dataset with firms that participated in the 2012 and 2014 waves of the Danish Research and Innovation Survey would have consisted of 1,104 firms after deleting observations with missing and extreme values.

activities were excluded, the pooled cross section had 6611 unweighted observations (11162 weighted observations). Of these, 2175 (3643) were from the 2012 wave, 2214 (3608) from the 2013 wave and 2222 (3911) from the 2014 wave.

4.4.2. DEPENDENT VARIABLE

Like in previous work conducted by the author (Guerrero, 2020), binomial logistic regressions were run on the likelihood that firms reported having collaborated on innovation with one or more Danish universities as part of their innovation activities (*UNI*). This variable took a value of "1" if the firm reported collaboration with at least one of the eight higher education institutions with full university status in Denmark as listed in the Danish Research and Innovation Survey *and* reported that this collaboration was relevant for its innovation activities; it took a value of "0" if any of these two conditions were not fulfilled. The names and geographical location of these institutions are specified in Figure 1. Positive values in *UNI* should include relationships closer to university-industry links where university researchers and industrial partners are actively involved, although more passive links like those involving the training of university students in firms might also be included (Perkmann & Walsh, 2007).

4.4.3. EXPLANATORY VARIABLES

Respondents in the Danish Research and Innovation Survey were asked to specify if their firms had collaborated with authorised technological service institutes. Because of their characteristics, the authorised technological service institutes could be classified as Danish RTOs. Whereas universities tend to focus on research and education, the authorised technological service institutes have a stronger orientation towards the provision of consultancy and testing services to firms, even if the activities of these two types of organisations might overlap to some extent. Table A1 in the Appendix shows the names of these institutes and the municipalities hosting their offices. When constructing *RTO*, firms that collaborated with authorised technological service institutes and that reported that this collaboration was relevant for their innovation activities were assigned "1"; a value of "0" was assigned if any of these conditions were not fulfilled.

The authorised technological service institutes are government-approved, not-for-profit institutes focused on diffusing new technologies among the Danish industries. As part of their mission, they combine applied research with the provision of services to firms, such as consultancy or testing services. Most of their earnings come from private sources, with a fraction coming from performance contracts with the Danish

government. Links between these organisations and universities are common, whether through informal links or formalised, collaborative research (Arnold et al., 2010, pp. 22–23; Åstrom, Eriksson, & Arnold, 2008, pp. 44–67; Nielsen, Christiansen, Boberg, & Rekve, 2018). Examples of formalised links are the general agreement between the network of authorised technological service institutes and the Technical University of Denmark (DTU)[30], the Danish universities' ownership of some of these institutes and the joint ownership together with Danish universities of research and testing facilities[31] (Åstrom et al., 2008, pp. 61–62).

RTO was connected with *REGION*, which reports the type of region where firms were located. Firms were assigned "0" if located in a metropolitan region, "1" if they were in a non-metropolitan university region and "2" if they were in a peripheral region. The reference category corresponded to firms in metropolitan regions. Firms were treated as belonging to a type of region depending on the municipality where their main workplace was located. The data to determine location was drawn from the IDA database.

The description of the regional classification was taken from Guerrero (2020), where the same regional classification was applied. A list of the functional urban areas of Denmark provided by the OECD was used, which also included the municipalities comprising urban areas (OECD, n.d.). The OECD defined functional urban areas as locations with at least 50000 inhabitants, including a core of densely populated contiguous municipalities in which at least 50% of the area had a population density equal to or above 1500 inhabitants/km^2 and an urban hinterland of municipalities in which at least 15% of the employed population commuted to work in the core municipalities. The OECD defined functional urban areas with 500000 inhabitants or more as metropolitan areas (OECD, 2012, pp. 29–34).

In Denmark, the OECD (n.d.) identified five functional urban areas (from largest to smallest): The municipalities of Copenhagen, Aarhus, Odense, Aalborg and Esbjerg, and the surrounding, commuting municipalities that belonged to their functional urban areas, as defined in the previous paragraph[32]. With an average population of 1838739 inhabitants between 2010 and 2014, Copenhagen was the only metropolitan area. At

[30] The strategic contract involved activities such as the exchange of staff, collaboration in R&D, and joint cooperation with firms (Åstrom, Eriksson, & Arnold, 2008, pp. 61–62).

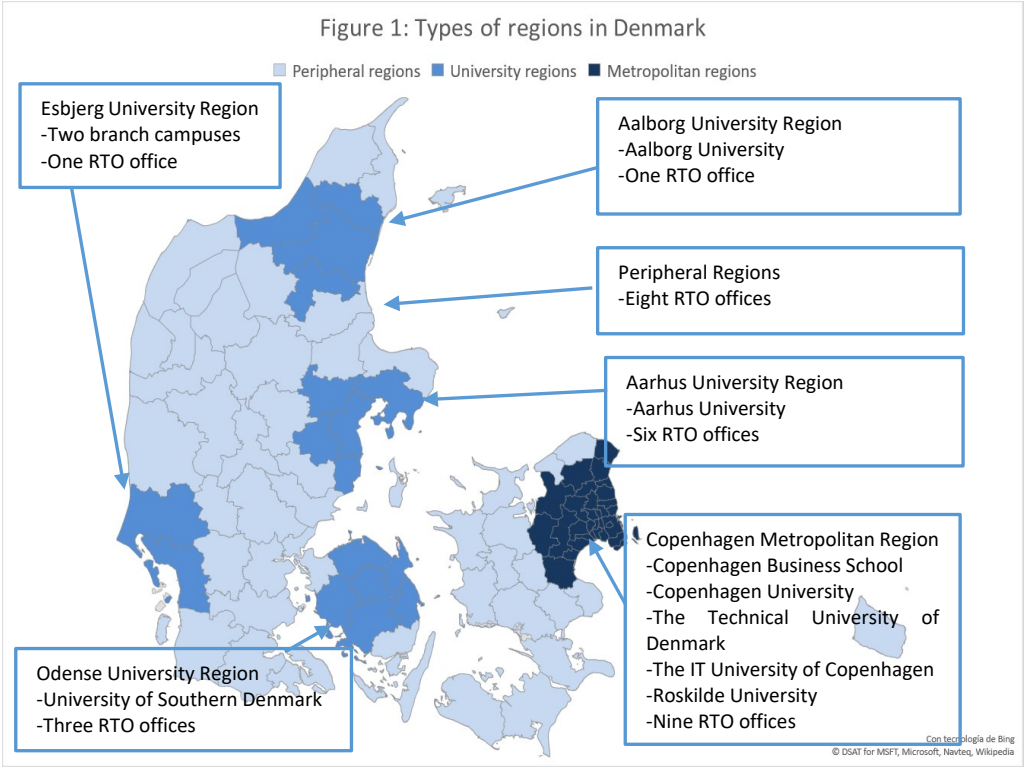
[31] DTU owns the Danish National Metrology institute, and the Bioneer institute, and Aarhus University owns the Alexandra institute. FORCE technology owns, together with DTU and Det Norske Veritas—a Norwegian certification institute—the Blade test centre, a testing facility for wind turbine blades (Åstrom et al., 2008, pp. 61–62).

[32] In January 2019, the OECD list of urban functional urban areas for Denmark (OECD, n.d.) was updated and no longer included the Esbjerg area; however the study used the previous list because the data covered the 2010–2014 period.

the other extreme, the Esbjerg area had an average population of 168518 inhabitants between 2010 and 2014 (Statistics Denmark, n.d.). The municipalities belonging to the Copenhagen metropolitan area were categorised as the Copenhagen metropolitan region, and the municipalities in other functional urban areas as non-metropolitan university regions. Municipalities that did not belong to any functional urban area were treated as peripheral regions. A map (Figure 1) shows the location of each type of region, as well as the number of universities and RTO premises that can be found in each type of region. Table A2 in the Appendix provides lists of the municipalities included in each functional urban area.

The peripheral regions' traits differed from those of urban regions and the Copenhagen metropolitan region. Figure 1 shows that the peripheral regions did not contain main university campuses; all non-metropolitan university regions except Esbjerg contained main university campuses, and the Copenhagen metropolitan region contained five universities (Danish Ministry of Higher Education and Science, n.d.). More differences are shown in section 4.4.5, which displays descriptive statistics for the sample.

Figure 1: Types of regions in Denmark



Sources: Danish Ministry of Higher Education and Science, n.d.; OECD, 2012, n.d.

4.4.4. CONTROL VARIABLES

Taking into account that firms that draw knowledge from a wide range of external knowledge sources are more likely to collaborate with universities (Hewitt-Dundas et al., 2019; Laursen & Salter, 2004), *COLLAB* reported the number of types of organisations that firms collaborated with as part of their innovative activities, excluding RTOs and universities. This variable was constructed from the same question as the one that identified collaboration with RTOs. The partner types included in *COLLAB* were suppliers, customers, competitors, firms in other industries, consultants, public actors, public service providers, public research institutions and other public partners. Affirmative responses to each one of these questions were coded as "1" if the respondent reported the collaboration to be relevant for the firm's innovation activities. The values were added up, ranging from "0" if firms reported no collaboration with any type of organisation and "9" if firms reported collaboration with all types. The approach applied when constructing *COLLAB* was similar to the one used in Guerrero (2020).

Secondly, *WAVE* controlled for the last wave of the Danish Research and Innovation Survey in which the firm was surveyed, the reference category corresponding to the 2012 wave.

Finally, the logistic regressions also included controls for the firms' structural characteristics. The values for the variables obtained from the IDA database were based on the data for the largest establishment in each firm:

- The average percentage of graduates in the company workforce over the period covered by the three waves (*SHAREGRAD*), whether firms applied for patents (*PATENTS*) and R&D spending as a percentage of sales (*RDSALES*) were included. These variables were used as proxies for the firms' absorptive capacity in the industry-university collaboration literature and take into account the finding that firms with higher absorptive capacity are more likely to collaborate with universities (Drejer & Østergaard, 2017; Laursen & Salter, 2004). *SHAREGRAD* and *RDSALES* were continuous variables, and *PATENTS* was a dichotomous variable that took the value of "1" for firms that reported applying for patents and "0", the reference category, for firms that reported applying for no patents. The data for *SHAREGRAD* were obtained from the IDA database, and the data for *PATENTS* from the Danish Research and Innovation Survey. *RDSALES* was based on data from the Danish Research and Innovation Survey combined with the IDA database. For this variable, I only included data for the last year of the corresponding wave of the survey for two reasons. Firstly, because the survey only enquired of firms for their amount of R&D spending in the survey year, calculating average R&D spending for a given period (e.g., between 2010 and 2012, for the 2012 wave) would have entailed including

only the 2010, 2011 and 2012 waves of the Danish Research and Innovation Survey, resulting in a lower number of observations. Secondly, the values for *RDSALES* did not change substantially over time (my own calculations, not shown). In order to avoid that the results were driven by outliers, those firms that reported R&D spending levels equivalent to more than 50% of their sales were excluded, following Laursen and Salter (2004) and Mohnen and Horeau (2003). These specifications of control variables have also been used in Guerrero (2020).

- The logarithm of the total number of employees (*LOGFIRMSIZE*) was used as a proxy for firm size (Drejer & Østergaard, 2017; Laursen & Salter, 2004). The data for this variable came from the IDA database and was an average for the period covered in the corresponding wave of the Danish Research and Innovation Survey. This specification of the control variable had also been used in Guerrero (2020).

- Pavitt's sectoral taxonomy (1984) highlighted that firms differed on the extent to which innovation was based on scientific research and R&D work, these knowledge sources being crucial for science-based sectors. In the present paper, an update of Pavitt's taxonomy (Bogliacino & Pianta, 2016) was used to classify the observations by sector. This classification added service and ICT-intensive activities in Pavitt's taxonomy and was amenable to the use of NACE Rev. 2 codes, which have been used by Statistics Denmark to classify workplaces' activity sectors since 2007. *SECTOR* thus classified firms in four categories: supplier dominated (0), scale and information intensive (1), specialised suppliers (2) and science based (3). The reference category was that of specialised suppliers. The data for *SECTOR* was from the IDA database and covered only the last year for the corresponding wave of the Danish Research and Innovation Survey; however, *WAVE* controlled for inter-year variations in the wave when the firm was surveyed. Table A3 in the Appendix provides information about the NACE two-digit codes aggregated in each *SECTOR* category.

Model 1 tests Hypothesis 1 including *RTO* as the explanatory variable. Model 2 tests Hypotheses 2, including an interaction term between *REGION* and *RTO*:

Model 1: $UNI_i = \alpha + \beta_{1REGIONi} + \beta_{2RTOi} + \beta_{3COLLABi} + \beta_{4RDSALESi} + \beta_{5PATENTSi} + \beta_{6LOGFIRMSIZEi} + \beta_{7SECTORi} + \beta_{8WAVEi} + \varepsilon_i$

Model 2: $UNI_i = \alpha + \beta_{1REGIONi} + \beta_{2RTOi} + \beta_{3(REGION*RTO)i} + \beta_{4COLLABi} + \beta_{5RDSALESi} + \beta_{6PATENTSi} + \beta_{7LOGFIRMSIZEi} + \beta_{8SECTORi} + \beta_{9WAVEi} + \varepsilon_i$

Correlation matrices and variance inflation factor tests were run, revealing no multicollinearity issues. A correlation matrix is available in the Appendix (Table A4).

4.4.5. DESCRIPTIVES

Table 1 provides descriptive statistics on the sample, showing that a higher percentage of firms in non-metropolitan university regions collaborated with universities on innovation (8.61%), compared to peripheral regions and the Copenhagen metropolitan region. A different pattern was observed concerning collaboration with RTOs on innovation; 8.29% of firms in peripheral regions collaborated with this type of organisation, well above university regions and the Copenhagen metropolitan region, which displayed the lowest percentage of firms collaborating with RTOs (3.78%).

Table 1: Sample descriptive statistics, characteristics by type of region (N=11162)	**Firms in the Copenhagen metropolitan region (N=4681)**		**Firms in non-metropolitan university regions (N=2674)**		**Firms in peripheral regions (N=3807)**	
	Mean	**Std dev**	**Mean**	**Std dev**	**Mean**	**Std dev**
UNI (dichotomous)	0,0652	0,3297	0,0861	0,3603	0,0737	0,3317
RTO (dichotomous)	0,0378	0,2547	0,0641	0,3146	0,0829	0,3501
COLLAB (continuous)	0,7556	2,1187	0,8213	2,1444	0,7881	2,0645
RDSALES (continuous)	3,0858	10,9824	3,0438	10,9946	1,4129	6,6891
SHAREGRAD (continuous)	21,9742	35,2627	15,9672	30,0971	7,6895	18,2749
LOGFIRMSIZE (continuous)	2,4530	1,5932	2,5183	1,5149	2,6888	1,4354
PATENTS (dichotomous)	0,0540	0,3020	0,0747	0,3376	0,0594	0,3000
SECTOR: Supplier dominated (dichotomous)	0,3366	0,6311	0,4228	0,6344	0,5163	0,6344
SECTOR: Scale and information intensive (dichotomous)	0,1174	0,4298	0,0905	0,3685	0,0888	0,3611
SECTOR: Specialised supplier (dichotomous)	0,3015	0,6128	0,2888	0,5821	0,2866	0,5741
SECTOR: Science based (dichotomous)	0,2446	0,5740	0,1978	0,5116	0,1083	0,3946
Number of observations						
WAVE 2010-12	1444		872		1328	
WAVE 2011-13	1531		860		1217	
WAVE 2012-14	1706		942		1262	

Other relevant differences concerned some of the variables that controlled for the firms' absorptive capacity and the distribution of firms by sector. Firms' R&D

spending over sales and firms' percentage of graduates was higher in metropolitan regions than in university regions and peripheral regions. Whereas supplier dominated firms were more common in peripheral regions, firms operating in the science-based sector were more common in the Copenhagen metropolitan region.

Table 2 provides a closer look at the extent to which firms combined collaboration with universities and RTOs, comparing the percentage of firms that collaborated with RTOs with the percentage of firms that collaborated with RTOs *and universities*. A higher percentage of firms in the Copenhagen metropolitan region that collaborated with RTOs collaborated as well with universities when compared to firms in the other types of regions; it was in peripheral regions where collaboration with RTOs and universities coincided the least.

Table 2: Firms that collaborate with RTOs. Percentage that collaborate with Danish universities, percentage that do not collaborate with Danish universities	**Firms in the Copenhagen metropolitan region (N=177)**	**Firms in non-metropolitan university regions (N=171)**	**Firms in peripheral regions (N=316)**
Collaborates with RTOs, but not universities	38.81%	55.05%	58.36%
Collaborates with RTOs, and universities	61.19%	44.95%	41.64%

4.5. RESULTS

4.5.1. LOGISTIC REGRESSIONS

The results of Model 1, provided in Table 3, support Hypothesis 1 ("*Firms that collaborate with RTOs are more likely to collaborate with universities when compared to firms that do not collaborate with RTOs."*), since the coefficient for *RTO* was statistically significant below the 1% threshold and had a positive sign. The model thus suggested that collaboration with RTOs was positively associated with collaboration with universities. However, the estimates cannot give *per se* an idea about how likely it was that firms collaborated with universities if they collaborated with RTOs, compared to firms that did not collaborate with RTOs. Predicted probabilities were thus requested, showing that for a firm with average values in the continuous control variables and reference values in the categorical control variables, the predicted probability of collaborating with universities on innovation was equal to

4.48% if collaborating on innovation with RTOs and 1.52% if not doing so. Note that because the explanatory and dependent variables covered the same period, the positive statistical association between collaborating with RTOs and collaborating with universities on innovation cannot be interpreted as a causal relationship.

Table 3: Logistic regressions, collaboration with universities in Denmark (sample with all types of regions)		**Model 1**	**Model 2**
Benchmark	Intercept	-5.9015***	-6.0431***
REGION (Copenhagen)	REGION (Non-metropolitan university)	0.3226***	1.8268***
	REGION (Peripheral)	0.3684***	0.6050***
RTO (No collaboration)	RTO (Collaboration)	1.1149***	0.4182***
REGION (Copenhagen)*RTO	REGION (Non-metropolitan university)*RTO		-1.5779***
	REGION (Peripheral)*RTO		-0.5908**
	COLLAB	0.6743***	0.6809***
	RDSALES	0.0447***	0.0443***
	SHAREGRAD	0.0146***	0.0149***
No patents	PATENTS	0.9736***	0.9910***
	LOGFIRMSIZE	0.3370***	0.3359***
SECTOR (Specialised supplier)	SECTOR (Supplier dominated)	-0.0723	-0.0293
	SECTOR (Scale and information intensive)	-0.7844***	-0.8295***
	SECTOR (Science based)	-0.1450	-0.1912
WAVE 2010-2012	WAVE 2011-2013	0.2226*	0.2672**
	WAVE 2012-2014	0.6651***	0.6978***
	N	11162	11162
	AIC	3257.427	3230.965
	SC	3352.578	3339.709
	-2 Log L	3229.427	3198.965
*: significant at 10% level, **: significant at 5% level, ***: significant at 1% level			

Moving to Model 2, Hypothesis 2 was not supported ("*Firms in peripheral regions that collaborate with RTOs are more likely to collaborate with universities, when compared to similar firms in metropolitan regions."*). Although both *RTO* and *REGION (Peripheral)* were statistically significant below the 1% threshold and had a positive sign, the interaction term *REGION (Peripheral)*RTO* had a negative sign and

was statistically significant below the 5% threshold. Therefore, there were no indications of a positive mediating effect between collaborating with RTOs and a firm's location in a peripheral region. The findings were similar for *REGION (University)* and the interaction term *REGION (University)*RTO*. Model 2 also suggested that there was no positive mediating effect between being located in an university region and collaborating with RTOs.

To assess the robustness of the findings, I provide in Table 4 the estimates of *RTO* in split samples for each type of region, together with its average marginal effects (AMEs). The AMEs show how much the probability of the outcome of interest (here, *UNI*=1) would increase if the value of the explanatory variable of interest, *RTO,* changed from 0 to 1 for all the observations in the split sample (Bogers, 2017; Karaca-Mandic, Norton, & Dowd, 2012; Leeper, 2017).

Although *RTO* has a positive sign in all the samples in Table 4, it was only in the models for firms in peripheral regions and for firms in the Copenhagen metropolitan region that *RTO* was statistically significant. Moreover, whereas the AMEs for the samples of firms in peripheral and metropolitan regions were statistically significant below the 1% threshold and similar in size, the AME for the sample of firms in non-metropolitan university regions was statistically insignificant, and its size was well below those of firms in peripheral and metropolitan regions. Collaboration with RTOs was associated on average with a 11.01% higher probability of collaborating with universities for firms in peripheral regions, and with a 10.89% higher probability for firms in the Copenhagen metropolitan region. The full models are displayed in the Appendix in Table A5.

Concerning firms in non-metropolitan university regions, Table 4 not only shows a lack of positive mediating effects between being located in this type of region and collaborating with RTOs. Among firms in non-metropolitan university regions, collaborating with RTOs was not positively associated with collaborating with universities. The results could suggest that in non-metropolitan university regions, unplanned interactions between firms' personnel and that of other organisations might provide as much experience on how to overcome the barriers for collaboration with universities as in metropolitan regions, owing to the variety of organisations present in metropolitan regions. However, another explanation could be put forward, based on the presence of universities in non-metropolitan university regions (Eder, 2019). Previous research has pointed out that universities in non-metropolitan university regions are often committed to support regional firms' innovation through education and research activities (Boucher, Conway, & Van Der Meer, 2003; Nilsson, 2006). These universities can also support existing clusters of science-based firms or promote the creation of new ones (Guerrero & Evers, 2018). In other words, the activities conducted by universities in non-metropolitan regions entail that industry-university collaboration is more likely to occur without the mediation of RTOs in these types of regions.

Table 4: Logistic regressions, collaboration with universities in Denmark (samples by type of region, extract of selected results)	**Model 3: Firms in peripheral regions**	**Model 4: Firms in non-metropolitan university regions**	**Model 5: Firms in the Copenhagen metropolitan region**
Intercept	-6.5863***	-5.6956***	-5.4562***
RTO (Estimate split samples)	1.4757***	0.0953	1.7138***
RTO (Average marginal effects)	0.1101***	0.0063	0.1089***
N	4681	2674	3807
AIC	1084.502	921.237	1058.821
SC	1153.714	985.934	1129.299
-2 Log L	1060.502	897.237	1034.821
*: significant at 10% level, **: significant at 5% level, ***: significant at 1% level			

In Models 1 and 2, the control variables largely follow the direction expected in the literature. As observed in previous research on industry-university collaboration, firms that collaborate with different types of non-university organisations are more likely to collaborate with universities (Laursen & Salter, 2004). Concerning firms' characteristics, larger firms are more likely to collaborate with universities (Mohnen & Hoareau, 2003; Segarra-Blasco & Arauzo-Carod, 2008). The same goes for firms with a higher absorptive capacity, regardless of whether the variable is R&D spending over sales (Laursen & Salter, 2004), the percentage of employees holding a university degree (Drejer & Østergaard, 2017) or whether the firm has applied for patents (Mohnen & Hoareau, 2003). Note that the association between the control variables and *UNI* might also have to do with the fact that the sample firms are innovative firms. As shown in the literature (Hewitt-Dundas et al., 2019; Mohnen & Hoareau, 2003) and in Table A6 in the Appendix where innovative and non-innovative firms are compared, the characteristics of innovative firms largely overlap with characteristics that are positively associated with industry-university collaboration. These characteristics include: high absorptive capacity, large size (Hewitt-Dundas et al., 2019; Laursen & Salter, 2004; Mohnen & Hoareau, 2003) and affiliation in sectors where science is a source of innovation (Laursen & Salter, 2004; Mohnen & Hoareau, 2003; Pavitt, 1984). Compared to non-innovative firms, fewer innovative firms were present in peripheral regions, while more of them were in university regions and the Copenhagen metropolitan region.

4.5.2. SENSITIVITY ANALYSES

Firms in a supplier-dominated sector have been observed to show a lower propensity to draw on universities for innovation, compared to firms in sectors like those that are science based or with a specialised supplier (Bogliacino & Pianta, 2016; Pavitt, 1984). An additional model tested whether the association observed in Model 2, between *REGION (Peripheral)*RTO* and *UNI* might be explained by differences in sectoral composition between the different types of regions. The model (not displayed due to space limitations; detailed results available upon request) added an interaction term between *REGION* and *SECTOR*. Compared to Model 2, the sign and statistical significance of *REGION (Peripheral)*RTO* did not change.

Firms are more likely to collaborate with universities and other organisations on innovation if they have received support from governmental schemes (Mohnen & Hoareau, 2003). Public subsidies have to compensate for the costs involved in financing collaborative research with universities (Bruneel, D'Este, & Salter, 2016). Hence, it could be that public subsidies support collaboration between firms and universities with the involvement of RTOs. An additional model tested whether the association between *RTO* and *UNI* and the association between *REGION (Peripheral)*RTO* and *UNI* were explained by firms' access to public subsidies. The model (not displayed due to space limitations; detailed results available upon request) included *FUNDING*, a variable that captured the amount of external funding that firms received as a percentage of their sales as well as the interaction terms *REGION*FUNDING* and *RTO*FUNDING*. The sign and statistical significance of *RTO* and *REGION (Peripheral)*RTO* did not change.

Just like firms that collaborate with universities might do so because they are equipped to collaborate with different types of organisations (Hewitt-Dundas et al., 2019), firms that collaborate with RTOs might do so because they are also equipped to collaborate with different types of organisations. While *COLLAB* already controlled for firms' propensity to collaborate with other organisations than RTOs and universities[33], an additional model included the interaction term *RTO*COLLAB* (not displayed due to space limitations; detailed results available upon request). The sign and statistical significance of the explanatory variables did not change.

[33] As in Guerrero (2020), a version of the model included a quadratic term for *COLLAB (COLLABSQ)*, controlling whether there might be a quadratic relationship between the number of types of non-university organisations that a firm collaborated with, and its propensity to collaborate with universities. Although *COLLABSQ* was statistically significant and had a negative sign, its inclusion in the model had no implications for the sign and statistical significance of the explanatory variables. Hence, *COLLABSQ* was excluded in order to ensure the parsimony of the model.

Finally, an additional model was run in a sample of firms that covered the 2011 wave, the 2012 wave and the 2013 wave (not displayed due to space limitations; detailed results available upon request). Contrary to Model 2, *REGION (Peripheral)* was not statistically significant, and the same was true for *REGION (Peripheral)*RTO*. The results suggest that the findings from the regression analyses might be sensitive to the time period they cover. Nevertheless, firms in peripheral regions that collaborated with RTOs were, as in the original Model 2, not more likely to collaborate with universities than similar firms in the Copenhagen metropolitan region.

4.6. DISCUSSION AND CONCLUSION

4.6.1. RESULTS DISCUSSION

This research aimed at adding to the literature by exploring whether collaboration with RTOs was positively associated with industry-university collaboration, and whether collaboration with RTOs and collaboration with universities was mediated by firms' regional location. The study thus aimed at answering the following research questions:

"Is collaboration with RTOs on innovation positively associated with industry-university collaboration on innovation?"

"Does the association between collaboration with RTOs on innovation and industry-university collaboration on innovation vary depending on the type of region where firms are located?"

In connection to the first research question, Model 1 showed a positive association between firms' collaboration with RTOs and industry-university collaboration. A possible explanation for this finding is that RTOs might help to bridge the distance between firms and universities directly through collaborative research projects and because of the social ties connecting RTO researchers and universities. RTOs might also help to bridge the gap between firms and universities because the firms that collaborate with RTOs might acquire experience on how to collaborate with an organisation whose norms and incentive systems are not far from those of universities, eventually applying this experience in collaborations with universities. Either way, the character of RTOs as organisations whose norms and incentive systems are in-between those of firms and universities (Arnold et al., 2007, 2010; Giannopoulou et al., 2019) entail that firms that collaborate with RTOs are better equipped to collaborate with universities.

In connection to the second research question, Model 2 showed that the association between collaboration with RTOs and industry-university collaboration varied with regional location, yet not in a way that fits the expectations formulated in Hypothesis

2. Collaboration with RTOs was not more strongly associated with industry-university collaboration among firms in peripheral regions, compared to firms in the Copenhagen metropolitan region, despite the differences in organisational diversity between the two types of regions (Guerrero, 2020; Tödtling & Trippl, 2005, 2015; Zukauskaite et al., 2017)**.** A possible explanation for this finding might relate precisely to the differences in organisational diversity between peripheral regions and the Copenhagen metropolitan region. In the Copenhagen metropolitan region, it might be easier for firms to collaborate with innovation partners other than a university, owing to the region's relatively high levels of organisational diversity. On the other hand, in regions with narrower levels of organisational diversity, like peripheral regions, firms might be more inclined to establish collaborative arrangements with universities owing to the absence of potential collaboration partners in their region (Johnston & Huggins, 2016; Shearmur & Doloreux, 2016). Extra-regional collaboration channels with universities might be for them a way to deal with the lack of potential collaboration partners in their own region (Jakobsen & Lorentzen, 2015).

Among firms in non-metropolitan university regions, collaboration with RTOs was not positively associated with industry-university collaboration. A possible explanation for the findings is that collaboration with RTOs might not be as conducive for industry-university collaboration as in the other types of regions, because firms in such types of regions tend to be co-located with universities that are particularly proactive in supporting regional firms through collaborative research links (Guerrero & Evers, 2018; Nilsson, 2006). Note however that not all universities in university regions are necessarily inclined to develop collaborative links with regional firms (Boucher et al., 2003). In the case of Denmark, some universities outside the Copenhagen region, like Aalborg University, are known to have developed for decades a wide array of educational and research activities supporting innovation in regional firms. Other universities outside the Copenhagen metropolitan region, such as the University of Southern Denmark, started to increase their third mission activities later on (Gregersen, Linde, & Rasmussen, 2009). Furthermore, Danish universities differ in the extent to which their firm partners are located in the same region (Drejer, Holm, & Nielsen, 2014, pp. 62–69).

4.6.2. LIMITATIONS AND FURTHER RESEARCH

This paper can only provide preliminary explanations for the statistical associations identified in the regression analysis. Further research is required to understand better why collaboration between firms and RTOs was positively associated with industry-university collaboration among firms in peripheral and metropolitan regions but not among firms in university regions. After all, this paper used a cross-sectional dataset to identify factors potentially associated with industry-university collaboration, and it is beyond the scope of this study to unearth causal processes. Supplementary studies

using panel data could contribute to overcoming this limitation since the data for the explanatory and dependent variables would correspond to different points in time. The datasets should, however, have a number of observations large enough to run regression analyses with interaction terms like the ones included in this paper. A complementary approach could entail combining quantitative analyses with case studies on the processes that facilitate that firms in peripheral regions, non-metropolitan university regions and metropolitan regions start and develop collaborations with RTOs and universities and then collaborations with RTOs and universities might have stronger relations with each other.

In the paper, it was also suggested that among firms in university regions, collaboration with RTOs was not associated with collaboration with universities, because universities in university regions were proactive in establishing links with regional firms through, for instance, collaborative research. Further studies could run separate regression analyses on whether firms in each of the university regions are, if collaborating with RTOs, more likely to collaborate with the university located in their region. These studies could help to assess whether, for instance, collaboration with RTOs is not associated with collaboration with Aalborg University among firms in its region. This approach would not be without challenges, nevertheless. Because there would be fewer observations, it is less likely that the models could detect any relations between the explanatory and dependent variables. Moreover, case studies would still be necessary in order to explore how differences in university behaviour are conducive to the establishment of links between these universities and the firms of their regions without the mediation of RTOs.

Further research might also help to rule out alternative explanations for the findings identified in this paper. That firms in peripheral regions were as likely to collaborate with universities as their metropolitan counterparts might have to do with the fact that geographical distances in Denmark are relatively short, compared to other countries. Therefore, few peripheral regions in Denmark might be considered truly peripheral, from a geographical point of view; that is geographically isolated (Eder, 2019). In this context, many firms in peripheral regions might be at a commuting distance from a relatively broad range of organisations, all the more, if their managers are willing to cross longer geographical distances than metropolitan firms in order to interact with other organisations (Johnston & Huggins, 2016; Shearmur & Doloreux, 2016). This line of reasoning also brings non-metropolitan university regions closer to the Copenhagen metropolitan region in terms of organisational diversity. A supplementary study could explore the relevance of geographical distance for industry-university collaboration in Denmark, through comparative analyses with innovation survey data from similar, but larger countries, such as Norway or Sweden.

Comparative research might also be beneficial in order to assess how generalizable are the findings to other countries with different types of RTOs. Other countries like Norway have a strong network of RTOs with strong links to the national universities

(Fagerberg, Mowery, & Verspagen, 2009). SINTEF, the main research institute in Norway was linked to the Norwegian University of Science and Technology in 1996, when its parent organisation, the Norwegian Institute of Technology, was added to that university (Arnold et al., 2010; Åstrom et al., 2008; Nielsen et al., 2018).

Finally, Denmark has only one metropolitan region. It is unclear whether the associations observed in this study would hold for countries with more than one metropolitan region. Cross-country studies could explore how inter-regional differences in industry-university collaboration would hold in countries with more than one metropolitan region.

4.6.3. IMPLICATIONS FOR THE LITERATURE, ADVICE FOR POLICYMAKERS

The paper clearly has implications for the literature on industry-university collaboration (e.g., Drejer & Østergaard, 2017; Hewitt-Dundas et al., 2019; Johnston & Huggins, 2016). By collaborating with RTOs, firms appear to be better equipped to overcome the barriers for collaborating with universities. Moreover, the fact that RTOs' relevance appears to vary depending on the type of region suggests that different processes governing collaboration between firms and RTOs might be at work, offering an interesting avenue for further research.

The findings of the study can also be of use to policymakers. One of the intended roles of the Danish RTOs is to facilitate linkages between firms and universities, and the evidence reviewed in this paper suggests that firms are indeed able to fulfil this goal, in particular among firms in the Copenhagen metropolitan region and in peripheral regions (Åstrom et al., 2008, pp. 60–62). Among firms in these two types of regions, promoting collaboration between firms and RTOs might be a way of facilitating industry-university collaboration. Promoting industry-university collaboration among firms in peripheral regions might, in turn, be a way of incentivising innovation among firms in peripheral regions, supporting those policies that aim at tackling the increasing regional disparities in Denmark (Knudsen, Christensen, & Christensen, 2018). The findings might also be useful to policymakers in other countries. As noted in the introduction, policymakers see in universities an institution that can support innovation and regional development (Breznitz & Feldman, 2012; Charles, 2006; Uyarra, 2010). Yet, universities develop their regional mission in different types of regions, and the factors associated with industry-university collaboration might vary by type of region.

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Disclosure statement

Declarations of interest: none.

Appendix

Table A1: Danish RTOs, municipalities where they have offices (source: Approved technological institute websites, Nielsen et al., 2018)

Name	Specialisation	Premises
Alexandra institute	IT for public and private organisations	Aarhus, Copenhagen
Bioneer	Biomedicine, pharma, biotechnology, medical technology	Brøndby
DBI (The Danish Institute of Fire and Security Technology)	Security, fire saftey engineering and prevention	Aarhus, Fredericia, Frederikshavn, Hvidovre
DFM (Denmark's National Metrology Institute)	Calibration, metrology	Hørsholm
DHI (Institute for Water and Environment)	Water: Inland, marine, urban, industry	Aarhus, Hørsholm
Force technology	Maritime and construction, life science and processing, oil and gas, electronics, energy and environment, public sector	Aalborg Øst, Aarhus N, Brøndby, Esbjerg, Frederikshavn, Hørsholm, Kalundborg, Kgs. Lyngby, Middelfart, Munkebo, Nordborg, Odense C, Vejen
Danish technological institute	Construction, materials, production, life science, energy, agrofood	Aarhus, Høje-Taastrup, Odense, Skejby, Sønder Stenderup

Table A2: List of Municipalities per Functional Urban Area	
Copenhagen Metropolitan Area	Albertslund, Allerød, Ballerup, Brøndby, Copenhagen, Dragør, Egedal, Fredensborg, Frederiksberg, Frederikssund, Furesø, Gentofte, Gladsaxe, Glostrup, Greve, Helsingør, Herlev, Hillerød, Hvidovre, Høje-Taastrup, Hørsholm, Ishøj, Køge, Lejre, Lyngby-Taarbæk, Roskilde, Rudersdal, Rødovre, Solrød, Tårnby, Vallensbæk
Aarhus	Aarhus, Favrskov, Odder, Skanderborg, Syddjurs
Odense	Assens, Faaborg-Midtfyn, Kerteminde, Nordfyns, Nyborg, Odense
Aalborg	Aalborg, Brønderslev, Jammerbugt, Rebild
Esbjerg	Esbjerg, Fanø, Varde

Source: OECD, n.d.

Table A3: Sectoral classification (source: Bogliacino & Pianta, 2016) (continues below)	**NACE Rev. 2, two-digit level code**
Science based	
Manufacture of chemicals and chemical products	20
Manufacture of basic pharmaceutical products and pharmaceutical prep.	21
Manufacture of computer, electronic and optical products	26
Telecommunications	61
Computer programming, consultancy and related activities	62
Scientific research and development	72
Specialised suppliers	
Manufacture of electrical equipment	27
Manufacture of machinery and equipment n.e.c.	28
Manufacture of other transport equipment	30
Repair and installation of machinery and equipment	33
Real estate activities	68
Legal and accounting activities	69
Management consultancy activities	70
Architectural and engineering activities; technical testing and analysis	71
Advertising and market research	73
Other professional, scientific and technical activities	74
Rental and leasing activities	77
Office administrative, office support and other business support activities	82
Scale and information intensive	
Manufacture of paper and paper products	17
Printing and reproduction of recorded media	18
Manufacture of coke and refined petroleum products	19
Manufacture of rubber and plastic products	22
Manufacture of other non-metallic mineral products	23
Manufacture of basic metals	24
Manufacture of motor vehicles, trailers and semi-trailers	29
Publishing activities	58
Audiovisual activities	59
Broadcasting activities	60
Information service activities	63
Financial service activities, except insurance and pension funding	64
Insurance, reinsurance and pension funding, except compulsory social security	65
Activities auxiliary to financial services and insurance activities	66

Table A3: Sectoral classification (final)	**NACE Rev. 2, two-digit level code**
Suppliers dominated	
Manufacture of food products	10
Manufacture of beverages	11
Manufacture of tobacco products	12
Manufacture of textiles	13
Manufacture of wearing apparel	14
Manufacture of leather and related products	15
Manufacture of wood and of products of wood and cork, except furniture	16
Manufacture of fabricated metal products, except machinery and equipment	25
Manufacture of furniture	31
Other manufacturing	32
Wholesale and retail trade and repair of motor vehicles and motorcycles	45
Wholesale trade, except of motor vehicles and motorcycles	46
Retail trade, except of motor vehicles and motorcycles	47
Land transport and transport via pipelines	49
Water transport	50
Air transport	51
Warehousing and support activities for transportation	52
Postal and courier activities	53
Accommodation and food service activities	55, 56
Veterinary activities	75
Employment activities	78
Travel agency, tour operator reservation service and related activities	79
Security and investigation activities	80
Services to buildings and landscape activities	81

Table A4: Correlation matrix of explanatory and control variables

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. REGION	1	0,1168***	0,0094	-0,0948***	-0,2676***	0,0396*	0,0863***	-0,1847***	-0,0313**
2. RTO		1	0,4675***	0,1077***	-0,0193	0,5556***	0,1039***	0,0982***	0,0149
3. COLLAB			1	0,2064***	0,1143***	0,1711***	0,0939***	0,0655***	0,0007
4. RDSALES				1	0,2145***	0,0975***	-0,1109***	0,2715***	0,0027
5. SHAREGRAD					1	0,0471***	-0,1278***	0,3148***	-0,0947
6. PATENTS						1	0,1795***	0,2275***	-0,0068
7. LOGFIRMSIZE							1	-0,2831***	-0,0392***
8. SECTOR								1	0,0147
9. WAVE									1

*: significant at 10% level, **: significant at 5% level, ***: significant at 1% level

Table A5: Logistic regressions, collaboration with universities in Denmark (samples by type of region, Average Marginal Effects)		**Model 6: Firms in peripheral regions**		**Model 7: Firms in non-metropolitan university regions**		**Model 8: Firms in the Copenhagen metropolitan region**	
		Average Marginal Effects	Confidence Intervals	Average Marginal Effects	Confidence Intervals	Average Marginal Effects	Confidence Intervals
Benchmark: RTO (No collaboration)	RTO (Collaboration)	0.1101***	[0.0748; 0.1454]	0.0063	[-0.0279; 0.0406]	0.1089***	[0.0643; 0.1536]
	COLLAB	0.0364***	[0.0323; 0.0405]	0.0485***	[0.0430; 0.0541]	0.0314***	[0.0281; 0.0348]
	SHAREGRAD	0.0026***	[0.0021; 0.0031]	0.0008***	[0.0003; 0.0013]	0.0002	[-0.0001; 0.0004]
Benchmark: No patents	PATENTS	0.0550***	[0.0203; 0.0898]	0.0725***	[0.0300; 0.01150]	0.0584***	[0.0295; 0.0873]
	RDSALES	0.0030***	[0.0017; 0.0043]	0.0015**	[0.0003; 0.0026]	0.0026***	[0.0020; 0.0032]
	LOGFIRMSIZE	0.0229***	[0.0140; 0.0318]	0.0270***	[0.0157; 0.0382]	0.0107***	[0.0048; 0.0167]
Benchmark: SECTOR (Specialised supplier)	SECTOR (Supplier dominated)	0.0096	[-0.0117; 0.0308]	0.0336**	[0.0056; 0.0617]	-0.0311***	[-0.0522; -0.0100]
	SECTOR (Scale and information intensive)	-0.0190	[-0.0531; 0.0150]	-0.0157	[-0.0613; 0.0298]	-0.0608***	[-0.081; -0.0386]
	SECTOR (Science based)	-0.0435***	[-0.0694; -0.0175]	0.0287*	[-0.0048; 0.0622]	-0.0204**	[-0.0401; -0.0006]
Benchmark: WAVE 2010-2012	WAVE 2011-2013	0.0118*	[-0.0013; 0.0390]	-0.0011	[-0.0296; 0.0273]	0.0160	[-0.0013; 0.0332]
	WAVE 2012-2014	0.0679***	[0.0457; 0.0900]	0.0334**	[0.0045; 0.0624]	0.0181	[0.0017; 0.0346]
*: significant at 10% level, **: significant at 5% level, ***: significant at 1% level							

Innovative firms might possess traits that are associated with a higher likelihood of collaborating with universities (Hewitt-Dundas et al., 2019; Mohnen & Hoareau, 2003). Hence, t-tests and chi-square tests were run to explore statistically significant differences between innovative and non-innovative firms in the explanatory and control variables (Table A6 in the Appendix). *COLLAB* was not included there because firms were only enquired about collaboration on innovation in the Danish Research and Innovation Survey. Innovative firms differed from their non-innovative counterparts in all the absorptive capacity controls. They were, on average more R&D

intensive; a higher proportion of their workforce held university degrees, and more of these firms applied for patents. Other than that, innovative firms were on average larger than their non-innovative equivalents, and more of them operated in the science-based, specialised supplier and scale- and information-intensive sectors. In contrast, a smaller proportion could be classified as supplier dominated.

Table A6: Descriptive statistics, differences between innovative and non-innovative firms	**Innovative firms (N=11162)**		**Non-innovative firms (N=13548)**		**Chi-square tests, T-tests**
	Mean	Std Dev	Mean	Std dev	*: significant 10% level, **: significant 5% level, ***: significant 1% level
RDSALES (continuous)	2,5052	9,7250	0,2698	4,2873	***
SHAREGRAD (continuous)	15,6635	30,0026	10,4633	31,2037	***
LOGFIRMSIZE (continuous)	2,5491	1,5248	2,4121	1,6316	***
PATENTS (dichotomous)	0,0608	0,3106	0,0053	0,1192	***
SECTOR: Supplier dominated (dichotomous)	0,4185	0,6411	0,5209	0,4825	***
SECTOR: Scale and information intensive (dichotomous)	0,1012	0,3919	0,0956	0,4825	***
SECTOR: Specialised supplier (dichotomous)	0,2934	0,5917	0,2809	0,7375	**
SECTOR: Science based (dichotomous)	0,1869	0,5066	0,1029	0,4979	***
REGION: Peripheral (dichotomous)	0,3411	0,6161	0,3871	0,7992	***
REGION: Non-metropolitan university (dichotomous)	0,2395	0,5546	0,2258	0,6861	*
REGION: Copenhagen (dichotomous)	0,4194	0,6413	0,3872	0,7993	***

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PART IV: FACTORS RELATED TO THE START, AND UNFOLDING OF INDUSTRY-UNIVERSITY COLLABORATION, IN NON-METROPOLITAN REGIONS

CHAPTER 5. PAPER D. SME–UNIVERSITY COLLABORATION IN NON-METROPOLITAN REGIONS: A MULTIPLE CASE STUDY ANALYSIS OF HOW COLLABORATIONS START AND UNFOLD

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5.1. ABSTRACT

The industry-university collaboration literature has studied the factors that are positively related to industry-university collaboration; however, not much is known about the relevance of these factors in different types of regions. Similarly, not much is known about the factors that are related to the initiation of collaboration with universities; and its unfolding. In order to help fill these gaps in the literature, the present study discusses the results of a multiple case study aimed at uncovering factors associated with the initiation and unfolding of industry-university collaboration among 7 SMEs operating in non-metropolitan regions of Denmark, Norway and Portugal. In order to highlight factors specific to the non-metropolitan SMEs, the case study also includes 4 cases of SMEs in metropolitan regions of the same countries. Among the non-metropolitan cases, the local universities play an active role in starting relations with the focal SMEs. These relations later on evolve, incentivised by the goal of satisfying international customers and supported by public funds, from non-collaborative relations such as student internships into collaborative research. Having an R&D department helps the non-metropolitan SMEs integrate university knowledge, and these firms developed their R&D departments while building on their collaboration with the focal university. The findings from the case studies contribute to the industry-university collaboration literature, by pointing out at factors associated with the initiation, and unfolding of industry-university collaboration among firms in non-metropolitan regions.

5.2. INTRODUCTION

Over the last decades, governments have been developing policies to stimulate firm–university collaboration with the goal of promoting firm innovation and reducing regional economic disparities (Charles, 2006). In non-metropolitan regions, such policies are enacted in an environment where there is typically one main university campus or a few branch campuses (Boucher et al., 2003; Charles, 2016; Eder, 2019; Trippl et al., 2018). Moreover, industry–university relations in non-metropolitan regions are influenced by a thin labour market for university graduates, with a relatively small proportion of university graduates in the regional labour force (Ahlin et al., 2014; Evers, 2019; Faggian and Mccann, 2009) or a relatively high proportion of firms from sectors that have not traditionally relied on university knowledge (Jauhiainen and Moilanen, 2012; Tödtling and Trippl, 2005, 2015). Thus, to a certain extent, non-metropolitan regions can be regarded as an economic periphery in relation to metropolitan centres (Eder, 2019). However, local universities in non-metropolitan regions have also played a key role as regionally engaged innovation partners providing regional firms with otherwise not readily available research capabilities (Alpaydin et al., 2018; Boucher et al., 2003; Fonseca and Çinar, 2017; Guerrero and Evers, 2018[34]).

Most of the literature on the drivers of industry–university collaboration has not addressed explicitly how factors associated with industry–university collaboration might relate to firm–university collaboration in different types of regions (D'Este et al., 2013; D'Este and Iammarino, 2010; Hewitt-Dundas et al., 2019). Nevertheless, Guerrero (2020a)[35] and Guerrero (2020b)[36] observed that firms in non-metropolitan regions of Denmark that have a main university campus are more likely than firms in the Copenhagen metropolitan region to collaborate with universities, whereas firms in non-metropolitan regions without a main university campus are as likely as their metropolitan counterparts to collaborate with universities.

However, little is known about the factors that influence collaborations between firms in non-metropolitan regions and universities. Most of the firms in non-metropolitan regions are small and medium-sized enterprises (SMEs) (Tödtling and Trippl, 2005, 2015), and SMEs are less likely than larger firms to collaborate with universities (Laursen and Salter, 2004; Segarra-Blasco and Arauzo-Carod, 2008). Compared to metropolitan regions, firms in sectors that have not traditionally relied on university knowledge dominate non-metropolitan regions (Jauhiainen and Moilanen, 2012; Tödtling and Trippl, 2005, 2015).

[34] Paper A in the thesis.

[35] Paper B in the thesis.

[36] Paper C in the thesis.

The present multiple case study was aimed at contributing to the industry–university collaboration literature by exploring which factors are positively associated with industry–university collaboration on innovation in non-metropolitan regions. Further, the study explored which factors are positively associated with the initiation of industry–university collaborations in non-metropolitan regions and which factors are positively associated with the unfolding of these collaborations. Thus, the study explored the following question:

Which factors are associated with the initiation and unfolding of industry–university collaboration on innovation in non-metropolitan regions?

The literature has identified a group of factors that are positively associated with industry–university collaboration. A multiple case study approach would allow for exploring whether these factors are positively associated with the initiation of collaborations between the case firms and universities or the unfolding of these collaborations. The multiple case study design would also allow for exploring the ways in which these factors might be positively associated with industry–university collaboration at each stage of the industry–university collaboration process.

The main findings of the study are as follows: (i) Local universities play a key role in initiating what will become industry–university collaborations, with university researchers approaching the case firm or the firm being invited to events aimed at promoting industry–university links. Universities' initial attempts to approach the case firms can be supported by the information that interns provide to university professors regarding the firms' research capabilities. (ii) The goal of developing products that are attractive to international customers incentivises the case firms to develop their relationships with universities from non-collaborative links (e.g. hosting employees, commissioned research) to full-fledged collaborative research – that is, relationships where both parties engage in research and development (R&D) work. (iii) Public funding schemes support the transition to collaborative research, providing resources for making investments in organisational resources that firms must commit. (iv) Having an R&D department helps the case firms integrate university knowledge, and each case firm developed its R&D department while building on its collaboration with the focal university. These commonalities stand among non-metropolitan case firms even if they differ in aspects such as the firm's activity sector, the exact format of the collaborative research in which the focal firm and university are currently involved and the types of public funding schemes that support such collaborative research.

The paper is structured as follows. The next section presents the literature review and the third section outlines the research methods. Next, the empirical context is discussed. The fifth section presents the empirical analysis. Afterwards, the findings are discussed. The final section concludes.

5.3. LITERATURE REVIEW: FACTORS RELATED TO INDUSTRY–UNIVERSITY COLLABORATION IN NON-METROPOLITAN REGIONS

5.3.1. CHARACTERISTICS OF NON-METROPOLITAN REGIONS AND THEIR POTENTIAL IMPLICATIONS FOR INDUSTRY–UNIVERSITY COLLABORATION

Non-metropolitan regions are locations beyond the commuting reach of a metropolitan agglomeration, which can include areas with at least one urban agglomeration containing a main university campus. By contrast, metropolitan regions are home to larger urban agglomerations and multiple universities (Eder, 2019; Tödtling and Trippl, 2015; Trippl et al., 2018).

Non-metropolitan regions also tend to be home to a relatively small number of large firms, and firms in sectors that have not traditionally relied on universities to source knowledge are common. For instance, non-metropolitan regions might contain a relatively high proportion of SMEs such as machinery suppliers or fabricators of metal products (Pedersen, 2005; Teles et al., 2014; Tödtling and Trippl, 2005, 2015). Compared to firms that rely on university research as a usual component of their innovation strategies, firms in sectors that have not traditionally relied on universities are relatively unlikely to rely on R&D departments as part of their innovation strategies (Pavitt, 1984). Accordingly, having an R&D department has been found to be a predictor of industry–university collaboration (Laursen and Salter, 2004).

Moreover, non-metropolitan regions are organisationally thinner locations relative to metropolitan regions. In other words, compared to metropolitan regions, non-metropolitan regions have a smaller number and variety of knowledge-generating organisations, such as universities, research institutes and firms in different sectors (Trippl et al., 2015; Zukauskaite et al., 2017).

5.3.2. FACTORS ASSOCIATED WITH INDUSTRY–UNIVERSITY COLLABORATION

This section discusses a set of factors that the literature has identified as being associated with industry–university collaboration. These factors are the role of non-metropolitan universities as facilitators of industry–university collaboration, the role of university graduates in industry-university relations, firms' access to governmental support schemes and firms' relations with organisations other than universities. The literature review is intended to support the exploration of whether and how these factors are associated with the initiation of industry–university collaboration processes and their unfolding.

5.3.2.1 The role of non-metropolitan universities in facilitating industry–university collaboration

From the discussion in section 5.3.1, it might seem that non-metropolitan regions are a relatively unfavourable terrain for industry–university collaboration to take root; however, quantitative evidence suggests otherwise. In Norway, firms in non-metropolitan regions are more likely than their metropolitan counterparts to collaborate with universities (Jakobsen and Lorentzen, 2015). Evidence from Guerrero (2020a) and Guerrero (2020b) suggests that in Denmark, firms in non-metropolitan regions where there is a main university campus are more likely to collaborate with universities than firms in the Copenhagen metropolitan region, whereas firms in non-metropolitan regions without a main university campus are as likely as their metropolitan counterparts to collaborate with universities.

Universities in non-metropolitan regions can be a key regional source of knowledge that is otherwise scarcely available to local firms in the region (Boucher et al., 2003). Universities in non-metropolitan regions that are actively involved in regional development engage in this work through a broad range of actions connected to their third mission, such as training of graduates suited to the regional labour market, entrepreneurship training and spin-off formation, commissioned research services and collaborative research (Alpaydin et al., 2018; Charles, 2016; Evers, 2019; Fonseca and Çinar, 2017; Guerrero and Evers, 2018; Nilsson, 2006). The activities of these higher education institutions can be seen from the perspective of the entrepreneurial university concept, including different forms of technology transfer activities supporting innovation in local firms, such as contract research, consultancy, collaborative research or participation in cluster initiatives. These universities also tend to structure their educational mission in ways that support innovation in local firms by providing educational programmes and continuous training programmes suited to the firms' needs (Clark, 2004, 1998; Gjerding et al., 2006; Uyarra, 2010).

Yet not all universities in non-metropolitan regions are necessarily supporting innovation and development in the region's sectors. Universities might focus their efforts on strong, already established economic sectors in the region (Alpaydin et al., 2018), and in some non-metropolitan regions, the main economic actors, such as firm associations, might not be interested in establishing links with universities (Boucher et al., 2003). Despite these exceptions, the above discussion suggests that universities in non-metropolitan regions can play a key role in industry–university collaboration by performing actions that facilitate the initiation and unfolding of these collaborations.

5.3.2.2 Graduates' role in connecting firms and universities

The non-metropolitan universities in the study were founded in the 1970s and 1990s, and the rationale for establishing these institutions was related to providing university degrees in regions with limited access to this type of education, which enabled an increase in the capacity of regional firms to absorb new knowledge, innovate and interact with universities (Evers, 2019; Faggian and Mccann, 2009; Guerrero and Evers, 2018). However, while educational levels in these regions have increased in the last decades, a relatively small proportion of the local workforce holds a university degree as compared to metropolitan regions (Evers, 2019; Faggian and Mccann, 2009; Guerrero and Evers, 2018; see table 2 in section 5.5.2). This is so, in part, because non-metropolitan regions' thin labour markets offer a relatively poor fit between university graduates' qualifications and the jobs on offer. Consequently, a relatively large proportion of university graduates from non-metropolitan regions emigrate to the thicker labour markets of metropolitan regions, where they can find jobs that better fit their qualifications (Ahlin et al., 2014; Scott, 2010; Storper and Scott, 2009).

According to the literature, firms that employ university graduates are more likely to collaborate with university graduates because these graduates provide those firms with the capacity to acquire and assimilate university knowledge (Drejer and Østergaard, 2017; Laursen and Salter, 2004). The scarcity of university graduates in non-metropolitan regions, relative to metropolitan regions, can pose a challenge to non-metropolitan firms' ability to collaborate with universities.

5.3.2.3 The relevance of governmental support schemes

Firms that benefit from governmental support schemes are more likely to collaborate with universities (Mohnen and Hoareau, 2003; Segarra-Blasco and Arauzo-Carod, 2008). In addition, SMEs might have too little financial slack to become involved in collaborative relationships with universities (Bruneel et al., 2016), and public funding can provide them with access to the financial resources they need to conduct collaborative research with universities. In non-metropolitan regions, SMEs account for a relatively high proportion of firms (Tödtling and Trippl, 2005, 2015). Thus, governmental support schemes might be particularly relevant to incentivise the initiation and unfolding of industry–university collaboration among firms in non-metropolitan regions. Nevertheless, it is unclear how exactly these funding schemes might relate to the unfolding of industry–university collaboration. It might occur, for instance, that they are more relevant in attracting firms to the possibility of forging different types of (not necessarily collaborative) relationships with their home universities.

5.3.2.4 Relations with organisations other than universities

Guerrero (2020a, 2020b) considered that firms in non-metropolitan regions might source external knowledge that is useful for innovation by relying on collaboration channels with other organisations, which are often located outside of their region. As non-metropolitan regions are organisationally thinner than their metropolitan counterparts, firms in non-metropolitan locations might not have the partners they need locally to collaborate in their innovative activities. Consequently, firms in non-metropolitan regions might resort to extra-regional collaboration channels to access suitable collaboration partners (Drejer and Vinding, 2007; Fitjar and Rodríguez-Pose, 2011; Grillitsch and Nilsson, 2015; Jakobsen and Lorentzen, 2015). Given that firms are more likely to collaborate with universities if they are sourcing knowledge from other sources as well (Laursen and Salter, 2004), firms in non-metropolitan regions that collaborate with universities might do so while collaborating with other organisations beyond their region.

5.4. METHODOLOGY

5.4.1. CASE SELECTION

A multiple case study (Eisenhardt, 1989; Eisenhardt and Graebner, 2007) was developed to explore the processes behind the initiation and unfolding of industry–university collaboration for innovation among seven SMEs operating in sectors that have not traditionally relied on university research in the non-metropolitan regions of North Denmark, Rogaland (Norway) and Aveiro (Portugal). When this fieldwork was undertaken, the SMEs in North Denmark were collaborating with the region's university – namely, Aalborg University. Similarly, the Rogaland SMEs were collaborating with the University of Stavanger, and the Aveiro SMEs were collaborating with the University of Aveiro. The cases were selected with the goal of exploring the influence of factors related to the initiation and unfolding of industry–university collaboration among firms in non-metropolitan regions. The case firms had to be typical of firms in non-metropolitan regions in terms of their size and sectoral characteristics. Thus, they were selected if they were SMEs – that is, if they employed a workforce equal to or below 250 employees at the time of the study or when they began collaborating with the focal university, if records were available. The firms should not have operated either in branches corresponding to the 2-digit level codes of NACE rev. 2, which Drejer and Østergaard (2015) classified as high-tech manufacturing (i.e. 21 and 26 codes) and knowledge-intensive services (i.e. 50–51, 58–66, 69–75, 78, 80, 84–93 codes). Firms in these sectors were expected to traditionally rely on university research; therefore, they were excluded from the case selection (see Table A1, in the Appendix).

Additional case studies of SMEs in metropolitan regions of Denmark, Norway and Portugal (i.e. the metropolitan regions of Copenhagen, Oslo and Lisbon) collaborating with universities in the same or another metropolitan region[37] were also selected for comparison. When searching for SMEs in metropolitan regions, to maximise comparability with the non-metropolitan cases, the goal was also to identify firms operating in sectors that traditionally have not relied on university research. Note, however, that among the metropolitan firms that finally could be approached, two of them were operating in sectors that have traditionally relied on university research (DK4 M and PT3 M, see Table 1.2). Following a theoretical replication logic (Yin, 2014), the objective was to select metropolitan cases that differed in one key trait from the non-metropolitan cases – that is, their location in metropolitan regions. The purpose of this case selection strategy was to highlight any industry–university collaboration processes specifically involving firms in non-metropolitan regions.

In all cases, the focal SME was engaging in collaborative research projects aimed at supporting the firm's innovative activities with science, technology, engineering and mathematics (STEM) researchers employed at the partner university. Owing to the high degree of relational involvement in these firm–university links (Perkmann and Walsh, 2007), it was possible to track down how they started and unfolded over time. Using Perkmann and Walsh's (2007) classification of university–industry links, the relation of interest was defined as collaborative research, since this involves arrangements where firms and universities pursue joint R&D work. Arrangements where there was no joint R&D work, such as contract research and consultancy services commissioned by industrial clients, would not be counted as collaborative research. Note, however, that two cases (DK1 NM and NO1 NM, see Table 1.1; DK5 M, see Table 1.2) involved firms employing an industrial PhD or postdoc. Based on Perkmann and Walsh's (2007) classification, these industry–university links would be classified as human resource transfer activities due to their educational focus; yet they would also count as collaborative research due to the firm's and university's joint commitment to R&D work.

In Rogaland, the cases were approached through the managers in charge of external relations in the University of Stavanger's Faculty of Science and Technology, and the case studies in Aveiro and the Lisbon metropolitan region were approached through the University of Aveiro's technology transfer office. It was not possible to approach firms in the Oslo metropolitan region through managers or academics from the University of Stavanger; therefore, a search for cases was carried out through the research project database of the Norwegian Research Council, which is the main public funding organisation for R&D-based research projects in Norway (Norwegian

[37] The case in the Oslo region was a firm collaborating with the University of Bergen – that is, a university outside the Oslo metropolitan region. It was not possible to find cases in the Oslo region that met the size and sectoral criteria and were collaborating with universities in the same region.

Research Council, n.d.). This procedure resulted in the selection of case NO3 M. In Denmark, it was not possible to approach firms and researchers involved in collaborations through the liaison officers available at Aalborg University. To identify firms involved in collaborative research with Aalborg University, the Technical University of Denmark and the University of Copenhagen, it was necessary to perform a search through the websites of these universities[38]. The non-metropolitan firms that were finally approached were collaborating with Aalborg University, while the metropolitan firms were collaborating with the Technical University of Denmark.

Including cases from more than one non-metropolitan region and more than one country would increase the external validity of the case study (Yin, 2014), as this would allow for assessing the extent to which the processes observed might be relevant in non-metropolitan firms across several countries, rather than being shaped by country-specific factors. The goals of the multiple case study, thus, can be placed in between the categories of contextualised explanation and theory building as defined by Tsang (2013). As in case studies aimed at offering contextualised explanations, the case studies in this research were aimed at providing causal explanations that would be sensitive to their specific context. However, because the data were gathered from firms in three countries, with their specific national contexts, the case study was also aimed at developing explanations that would be transferable to more than one context, as in the theory-building case studies defined by Tsang (2013).

[38] The Technical University of Denmark and the University of Copenhagen were chosen because the former is the Copenhagen metropolitan region's technical university and the latter is the largest university in Denmark (Drejer and Østergaard, 2017, p. 1196).

Table 1.1 Data sources non-metropolitan cases (continues below)

	DK1 NM	DK2 NM	DK3 NM
Total number interviews	1	1	2
Interviewees focal firm (interview mode)	Industrial PhD DK1 NM (Skype)	CTO/co-owner, Manager DK2 NM (Telephone)	CEO; former CEO/owner DK3 NM (Face to face)
Role of interviewees focal firm in the collaboration	Carrying research work for the firm and the university, as part of his/her industrial PhD and, later on PostDoc	Coordinating research work at the firm, and collaboration with the university in general	Both: Coordinating research work at the firm, and collaboration with the university in general
Interviewees focal university (interview mode)	No	Same as focal firm, external lecturer at university	No
Document data	Press clippings, project description at funding organisation website, reports from company website	Press clippings, project description at funding organisation website, reports from company website	Press clippings, reports from company website
Type of university (main university)	Comprehensive with technical character (Aalborg University, AAU)	Comprehensive with technical character (Aalborg University, AAU)	Comprehensive with technical character (Aalborg University, AAU)
Type of STEM department involved in the collaboration	Department of Materials and Production. Faculty of Engineering and Science	Department of Materials and Production. Faculty of Engineering and Science	Department of Planning. Faculty of IT and Design

Table 1.1 Data sources non-metropolitan cases (final)				
	PT1 NM	**PT2 NM**	**NO1 NM**	**NO2 NM**
Total number interviews	3	3	3	2
Interviewees focal firm (interview mode)	CEO; HR manager PT1 NM (Face to face)	Innovation director PT2 NM (Face to face)	CTO NO1 NM (Face to face); CEO NO1 NM (Skype)	CEO NO2 NM (Skype); managing director partner firm NO2 NM (Face to face)
Role of interviewees focal firm in the collaboration	CEO: Coordinating research work at the firm, and collaboration with the university in general	Coordinating research work at the firm, and collaboration with the university in general	CTO: Industrial PhD. Coordinating firm research work, and collaboration with the university in general. CEO: Access support funds	Both: Coordinating research work at their firms, and collaboration project with the university
Interviewees focal university (interview mode)	Researcher PT1 NM, mechanical engineering dept (Face to face)	Researcher PT2 NM, mechanical engineering dept (Face to face)	Researcher NO1 NM, mechanical engineering dept (Face to face)	No
Document data	Press clippings, internal repports	Reports from company website	Press clippings, reports from company website	Reports from company website
Type of university (main university)	Comprehensive with technical character (University of Aveiro, UA)	Comprehensive with technical character (University of Aveiro, UA)	Comprehensive with technical character (University of Stavanger, UiS)	Comprehensive with technical character (University of Stavanger, UiS)
Type of STEM department involved in the collaboration	Mechanical Engineering Department (no faculties)	Mechanical Engineering Department (no faculties)	Department of Mechanical and Structural Engineering and Materials Science, Faculty of Science and Technology	Department of Energy and Petroleum Engineering, Faculty of Science and Technology

Table 1.2 Data sources, metropolitan cases				
	DK4 M	**DK5 M**	**PT3 M**	**NO3 M**
Total number of interviews	2	1	2	1
Interviewees from focal firms (interview mode)	CEO DK4 M (Skype)	CEO; COO DK5 M (Face-to-face)	Head Water department PT3 M (Face-to-face)	Innovation manager NO3 M (Skype)
Role of interviewees from focal firms in the collaboration	Coordinating research work at the firm and collaboration with the university in general	Both: Coordinating research work at the firm and collaboration with the university in general	Coordinating research work at the firm and collaboration with the university in general	Coordinating research work at the firm and collaboration with the university in general
Interviewees from focal universities (interview mode)	No	No	Researcher PT3 M, Biology Dept. University of Aveiro (Face-to-face)	No
Document data	Press clippings, project description on funding organisation website, reports from company website	Press clippings, project description on funding organisation website, reports from company website	Reports from company website	Press clippings, reports from company website
Type of university (main university)	Technical (Technical University of Denmark, DTU)	Technical (Technical University of Denmark, DTU)	Comprehensive with technical character (University of Évora, UE)	Comprehensive (University of Bergen, UiB); Norwegian water research institute, University of Stirling
Type of STEM department involved in the collaboration	National Institute of Aquatic Resources (no faculties)	Department of Mechanical Engineering (no faculties)	Department of Biology, School of Sciences and Technology	Faculty of Mathematics and Natural Sciences

5.4.2. DATA SOURCES

The data sources in each case were semi-structured interviews and document data, including internal reports, press clippings and information available on the firms' websites. The interviewees were labelled according to their role at the firm or university and the case in which they participated. For instance, "Owner DK3 NM" refers to the owner of the firm interviewed in the third Danish case (i.e. DK3 NM). The interviews were conducted mainly with top managers responsible for coordinating research work at their firm and collaboration with the focal university in general (i.e. beyond specific projects). However, one interviewee (Industrial PhD DK1 NM) had collaborated as an industrial PhD and was pursuing an industrial postdoc at the time of the interview. Another interviewee (CTO NO1 NM), at the time of the interview, was collaborating as an industrial PhD while also coordinating research work at the firm and collaboration with the university. In cases PT1 NM, PT2 NM, NO1 NM and PT3 M, semi-structured interviews were also conducted with university researchers who had collaborated on research projects with the case firms. This was done to gather information that firm managers could not provide (see Table 1.1). The document data enabled the triangulation of data gathered from the interviews and provided additional information about the firms' characteristics as well as the histories of their relationships with university partners.

Interviews with the Portuguese firm managers and researchers were conducted between April and June 2018, and follow-up interviews were carried out in June 2019 to gather more information about firms PT1 NM and PT2 NM (interviews with CEO PT1 NM and Researcher PT2 NM). As for the Danish and Norwegian cases, interviews with firm managers were carried out between April and June 2019. The interviews were conducted face-to-face whenever possible; however, Skype and phone conversations had to be arranged in 6 out of 21 instances. The interviews lasted between 30 and 90 minutes, and the interview guide (see Appendix) contained questions on the current status of the collaboration with the university as well as follow-up questions intended to explore how the relationship had started (Rubin and Rubin, 2005, pp. 137–146). Whenever the first interviewee could not recall how the relationship began, document data or interviews with other managers and researchers supplemented information on the initiation of these links. All interviews were recorded and transcribed, and notes were taken during the interviews.

5.4.3. RESEARCH PROCESS

Similar to other multiple case studies involving firms (Gilbert, 2005; Graebner and Eisenhardt, 2004), this investigation was informed by previous research, which aided in identifying factors that could influence processes that facilitate the initiation and unfolding of industry–university collaboration in non-metropolitan regions.

Previous research highlighted factors that could influence the industry–university collaboration process and whose influence could differ among different types of regions. These were (i) the propensity of universities in non-metropolitan regions to support innovation and development in regional industries through education and research activities (Guerrero and Evers, 2018); (ii) the educational and research actions through which these universities support regional industries (Guerrero and Evers, 2018); (iii) the observation that firms that employ university graduates are more likely to collaborate with university graduates, as these graduates provide firms with the capacity to acquire and assimilate university knowledge (Drejer and Østergaard, 2017; Laursen and Salter, 2004); (iv) the observation that firms in non-metropolitan regions might look to extra-regional collaboration channels to access suitable collaboration partners (Drejer and Vinding, 2007; Fitjar and Rodríguez-Pose, 2011; Grillitsch and Nilsson, 2015; Jakobsen and Lorentzen, 2015); (v) the finding that firms that access public funding are more likely to collaborate with universities (Mohnen and Hoareau, 2003; Segarra-Blasco and Arauzo-Carod, 2008); and (vi) the observation that geographical proximity is positively associated with industry–university collaboration (D'Este and Iammarino, 2010).

The factors reviewed in the literature were taken into account in the design of the interview guides for firm managers and university researchers. They explored, in the following order, (i) goals of the collaboration between the case firm and university, (ii) how the industry–university collaboration started and (iii) how this collaboration unfolded. Those factors that were easier to convey to the interviewees were made explicit in the interview guide, whereas those that were more difficult to convey were covered as the interview unfolded. The interview guides are provided in the Appendix.

This was a case study aimed at exploring whether and how factors highlighted by the literature as relevant to industry–university collaboration are positively associated with the initiation and unfolding of the industry–university collaboration process. Accordingly, when coding the interview transcripts and documents, the factors highlighted as relevant to industry–university collaboration in the literature also facilitated exploring what had influenced the formation of a relationship between the focal firm and university and how this relationship unfolded later on. Thus, special attention was paid in the first-order codes to paragraphs in the interviews and document data where these factors appeared to be relevant. Later on, first-order process-oriented codes were aggregated into theoretically laden themes following inductive theory development methods (Gilbert, 2005; Gioia et al., 2013; Saldaña, 2009). It should be noted that directing the coding process at factors highlighted in the literature as relevant to industry–university collaboration came at the expense of other potential factors not highlighted in the literature.

First, tabular displays were used to explore the influence of factors extracted from the literature review at the start of the relationship between each firm–university pair and at later stages. Second, cross-case comparisons were carried out to uncover

similarities among the non-metropolitan cases. Third, cross-case comparisons between the metropolitan cases and non-metropolitan cases were conducted to highlight which processes appeared to be specific to industry–university collaborations in non-metropolitan regions (Eisenhardt, 1989; Eisenhardt and Graebner, 2007; Gilbert, 2005). Thus, the study approach combined literal and theoretical replications to uncover processes which were common among the non-metropolitan cases, regardless of factors specific to the context of each non-metropolitan region and country, and how different they were from metropolitan cases (Tsang, 2013; Yin, 2014).

5.5. CONTEXT

5.5.1. NATIONAL INDUSTRY–UNIVERSITY COLLABORATION POLICIES

Considerable similarities exist between Danish and Norwegian industry–university collaboration policies, whereas these policies are arguably less supportive of industry–university collaboration in Portugal, as will be discussed below.

In Denmark, the implementation of a new university law in 2003 and the launch of the Danish Globalisation Strategy in 2006 meant a greater policy emphasis on third mission activities as well as a stronger emphasis on performance-oriented funding at the expense of basic funding (Fagerberg and Fosaas, 2014, p. 32; Kalpazidou Schmidt, 2012). Development contracts between the Ministry of Higher Education and Science (previously the Ministry of Science, Technology and Innovation) and universities have focused since 2010 on research performance indicators, such as the number and level of publications, but also on indicators of industry–university collaboration, such as the amount of external funds. These developments have been similar in Norway, where a formula-based funding system for education and research was introduced in 2002 that placed greater emphasis on educational outcomes and research performance (Kalpazidou Schmidt, 2012).

Similarly, both countries have a comparatively generous range of public funding schemes to support firm innovation and collaboration between firms and universities. These policies include the following:

- Network-based initiatives, such as the establishment in Denmark of 22 sector-based innovation networks and cross-sectoral innovation platforms (Knudsen et al., 2018), and schemes supporting the development of emerging, mature and internationally oriented clusters in Norway (Solberg, 2016).

- Schemes promoting firms' absorptive capacity and linkages with research organisations. In Denmark, this umbrella includes Innobooster, which helps SMEs in

hiring university-trained employees, or innovation vouchers which help SMEs purchase researcher services from universities. In Norway, various public funding schemes stimulate collaboration for innovation, with the Norwegian Research Council supporting R&D-based innovation activities and Innovation Norway focusing in non-R&D innovation (Knudsen et al., 2018; Solberg, 2016).

- Industrial PhD and postdoc programmes, with Denmark introducing industrial PhDs in 1970 and Norway following in 2008 with an industrial PhD programme inspired by that of Denmark (Grimpe, 2015; Solberg, 2016). In Denmark, an impact assessment conducted in 2011 concluded that the scheme increased firms' absorptive capacity while stimulating industry–university links (Grimpe, 2015). Similar results stemmed from an evaluation of the Norwegian industrial PhD programme conducted in 2012, although the review also pointed out that the programme had to be communicated further to firms and researchers (Solberg, 2016).

In contrast with its Scandinavian counterparts, the Portuguese policies are less supportive of industry–university collaboration, in part, because of the Portuguese economic context. Firms and universities have a relatively scarce tradition of cooperation. Low levels of absorptive capacity in the industrial fabric and effects of the economic crisis that have lingered for most of the past decade have further hampered industry–university links. Although public sector R&D spending decreased substantially between 2010 and 2014 owing to government budgetary cuts, the largest reduction in levels of R&D spending took place in the private sector. In recent years, policies have been implemented to stimulate industry–university links, including collaborative R&D networks encompassing R&D projects promoted by employers' associations and implemented by universities, and cluster initiatives. Commentators have pointed out, however, that this policy framework is too reliant on a supply-side approach, thus paying limited attention to the needs of firms. An exception to this supply-side bias might be the use of tax incentives to develop R&D (Corado Simões et al., 2018; Mira Godinho and Corado Simões, 2015). Yet, in a context marked by severe budgetary restrictions like that of Portugal, European Union (EU) cohesion policy funding for Smart Specialisation strategies or the FP7 and H2020 programmes might play a relevant role in supporting collaboration for innovation projects (Corado Simões et al., 2018; Mira Godinho and Corado Simões, 2015; Silva et al., 2016).

5.5.2. CONTEXT OF THE REGIONS AND UNIVERSITIES

As shown in Table 2, the regions of North Denmark, Rogaland and Aveiro host a smaller number of main university campuses than their metropolitan counterparts. More importantly, in these regions, a smaller percentage of the population is enrolled in universities compared to metropolitan regions. Therefore, universities provide education to a smaller percentage of the local population in non-metropolitan regions.

There are also substantial inter-regional differences in the proportion of the workforce that holds a university degree. Note, however, that metropolitan regions are home to multiple universities and governmental organisations, and the presence of these organisations might partially explain why a larger percentage of the populations of metropolitan regions hold a university degree. Finally, in non-metropolitan regions, a smaller proportion of the workforce is employed in medium and high-technology manufacturing and knowledge-intensive services compared to metropolitan regions, as measured according to the Regional Innovation Scoreboard.

Table 2: Regional characteristics (continues below)	**Norway**		**Denmark**		**Portugal**	
	Oslo metro. region	**Rogaland**	**Copenhagen metro. region**	**North Denmark**	**Lisbon metro. region**	**Aveiro region**
1. Population, 2017	1,271,127	472,024	1,807,404	587,335	2,821,349	363,752
2. Population density, 2017. Inhabitants/km^2	252.5	53.5	745.4	76.2	1,006.2	221.5
3. Number of universities per region	3	1	5	1	5	1
4. Students enrolled at the local universities, latest data available	56,070	12,000	79,214	19,926	111,294	13,000
5. Students enrolled at the local universities, as a percentage of the population	4.41%	2.54%	4.38%	3.39%	3.94%	3.57%

Sources: Rows 1, 2, 5: Eurostat (n.d.). Row 3: Bonfim et al. (2013); Danish Ministry of Higher Education and Science (n.d.), Government.no (n.d.). Rows 4, 5: Websites of the universities located in each region. Rows 1, 2: Data for the Oslo metropolitan region correspond to the counties of Oslo and Akershus.

Table 2: Regional characteristics (final)	Norway		Denmark		Portugal	
	Oslo metro. region	Rogaland	Copenhagen metro. region	North Denmark	Lisbon metro. region	Aveiro region
6. Percentage of firms that reported collaborating with universities between 2014 and 2016 (all of Norway; between 2012 and 2014 for the Danish regions due to data limitations)	20%		16.53%	20.41%	10.30%	10.30%
7. Percentage of the 25–64 age group with tertiary education, average 2007–2017 (Levels 5–8 ISCED 2011)	50.41%	35.63%	45.60%	28.21%	26.44%	16.56%
8. Percentage of the 25–64 age group with tertiary education, 2017 (Levels 5–8 ISCED 2011)	54.30%	39.80%	50.20%	31.70%	32.60%	22.50%
9. Percentage of the 25–64 age group with tertiary education, percentage increase 2007–2017 (Levels 5–8 ISCED 2011)	7.90%	7.60%	9.30%	8.20%	12.10%	10.70%
10. Employment in medium and high-technology manufacturing and in knowledge-intensive services as a percentage of the workforce. Score from the Regional Innovation Scoreboard 2017, compared to EU average 2011 (EU average 2011 = 100. Source: European Commission, 2019)	144.7	100.91	158.39	80.84	120.07	43.44

Sources: Row 6: Direção-Geral de Estatísticas da Educação e Ciência (n.d.), Statistics Norway (n.d.), own elaboration from Statistics Denmark microdata. Rows 7 to 9: Eurostat (n.d.). Row 10: European Commission (2019). Data for the Copenhagen metropolitan region correspond to the Capital Region of Denmark. Rows 6–10: Data for the Oslo metropolitan region correspond to the counties of Oslo and Akershus. Rows 6–10, data for Rogaland correspond to the sum of the Rogaland and Agder counties, and data for Aveiro correspond to the broader Centro Region.

The qualitative evidence also points to the non-metropolitan regions specialising in sectors that have not traditionally relied on university research, relative to the national economy. This is the case of machinery manufacturers in North Denmark and Rogaland and fabricators of metal products in Aveiro (Nilsson, 2006; Pedersen, 2005; Rodrigues and Teles, 2017; Teles et al., 2014). A similar percentage of firms collaborate with universities regardless of regional location, and more firms collaborate with universities in North Denmark than in the metropolitan region of Copenhagen.

The three non-metropolitan universities included in the present case study are young higher education institutions. The University of Aveiro was founded in 1973 (Nieth et al., 2018), Aalborg University in 1974 (Guerrero and Evers, 2018) and the University of Stavanger in 1994 as a university college, acquiring full university status in 2005 (Alpaydin et al., 2018). These universities have oriented their education and training activities to support innovation in regional firms and are regarded in their home regions as crucial innovation partners (Alpaydin et al., 2018; Fonseca and Çinar, 2017; Guerrero and Evers, 2018). In that regard, they differ from other universities in non-metropolitan regions that have not developed strong links with local firms (Boucher et al., 2003).

The origins of these higher education institutions are also connected to the regional firm demography at the time. The first premises of the University of Aveiro were at the Innovation Centre of Portugal Telecom, also launched in the early 1970s, and some of the first educational degrees awarded by the university were in the domains of electronics and communications and in disciplines related to sectors dominant in the region at that point in time, such as ceramics and materials for the ceramics industry, environment and marine sciences and technologies for fisheries, and natural and agro-food products for agriculture and farming (Fonseca and Çinar, 2017; Rodrigues and Teles, 2017). Similarly, the academic institutions that preceded the University of Stavanger developed educational degrees to cater to the needs of the growing oil and gas industry, which is currently the main economic sector in the region[39] (Alpaydin et al., 2018). Lastly, Aalborg University started as a merger of an engineering academy and other higher education institutions, with a strong focus on engineering and science degrees. Shortly after its foundation, it oriented its educational and research activities towards meeting the needs of the emerging information and communications technology (ICT) sector. Indeed, at its launch, the university had two departments in electronic engineering and employed 200 academic staff members. In 1979, the university founded the Department of Electronic Systems to train students according to the needs of this sector (Guerrero and Evers, 2018).

[39] Two of the academic institutions that would become part of the University of Stavanger (a regional college and a technical college) had already been offering degrees related to oil exploration since the 1970s (Alpaydin et al., 2018, p. 17).

Over time, these higher education institutions have developed educational and research activities that support the aforementioned sectors through links, such as research centres, science parks and cluster initiatives. These links, in turn, have contributed to the research excellence of Aalborg University in ICT (Guerrero and Evers, 2018), the University of Aveiro in building materials and ICT (Rodrigues and Teles, 2017) and the University of Stavanger in oil and gas (Alpaydin et al., 2018). These universities also endeavour to support the growth of new economic sectors in their home regions, with examples such as biomedical sciences at Aalborg University (Guerrero and Evers, 2018), aquaculture and marine biotechnology at the University of Aveiro (Rodrigues and Teles, 2017) and biomedicine and geothermal and offshore wind energy at the University of Stavanger (Alpaydin et al., 2018).

Beyond specific sectors, the three universities have committed considerable resources to activities for supporting innovation in regional firms, which can be readily accessible to SMEs from sectors not traditionally reliant on university research. These include student projects carried out in collaboration with firms and the development of intermediaries aimed at helping SMEs access consultancy services (Alpaydin et al., 2018; Fonseca and Çinar, 2017; Guerrero and Evers, 2018; Nieth and Benneworth, 2019; Rodrigues and Teles, 2017). For instance, Aalborg University's problem-based learning (PBL) approach to learning entails that students work in teams on self-defined, interdisciplinary projects, many of them related to challenges faced by local firms. Through these projects, firms can screen suitable candidates for their workforce, and PBL projects have increased the interest of SMEs in hiring Aalborg University graduates (Gregersen et al., 2009). The number of projects grew to the point that, in recent years, Aalborg University has continuously hosted between 2,000 and 3,000 of them (Kendrup, 2006, p. 25), and in 2016, 53.1% of the master's theses were done in collaboration with firms or other external partners (Aalborg University, 2016).

Note that the case universities' involvement in regional development has also been stimulated by their interactions with regional policymakers and the funding sources that might come from these interactions. On that note, the University of Aveiro worked with the local municipalities to define the region's development strategy (Rodrigues and Teles, 2017), and some of Aalborg University's third mission activities have received monetary support from North Denmark's Growth Forum – a multi-stakeholder economic governance body in charge of determining the allocation of regional development funds – as part of a knowledge dissemination agreement between these two parties (Lindqvist et al., 2012). An example is the funding that the Growth Forum provided for the establishment of the matchmaking network – a network of Aalborg University researchers, public and private sector officials and students aimed at facilitating firms' access to the university's research and educational services, in particular SMEs in the outermost areas of the region of North Denmark, with limited connections to Aalborg University (Nieth and Benneworth, 2019).

5.6. ANALYSIS

5.6.1. CASE OVERVIEW

Tables 3.1 and 3.2 present an overview of the analysed cases. At the time of the interviews, all but two firms could be considered SMEs. The exceptions are the firms in DK5 M and PT1 NM, yet these firms did not have more than 250 employees at the beginning of their relationship with the focal university. Another important similarity among the cases is that most of them had an R&D department by the time the interviews were conducted; PT1 NM and NO2 NM were the only exceptions. That most of the non-metropolitan case firms have an R&D department is in accordance with the expectations of the industry–university collaboration literature, because firms with R&D departments have been found to be more likely to collaborate with universities (Laursen and Salter, 2004). The possession of R&D departments might partially explain why these firms began and continued collaborating with universities. Section 5.6.5 will explore this point in depth. That most of the case firms have an R&D department becomes even more important when considering that these firms operate in sectors where R&D and university research have traditionally not played an important role in the development of new products, such as the manufacturing of components for the maritime industry (DK1 NM), the manufacturing of fabricated metal products (PT1 NM) or the manufacturing of machinery for oil and gas operators (NO1 NM, NO2 NM).

Table 3.1 Characteristics non-metropolitan cases (continues below)

	DK1 NM	**DK2 NM**	**DK3 NM**
Main activity at the focal firm	Machinery manufacturer for the maritime industry	Manufacturer of devices for people with special	Furniture manufacturer for the public sector
Nace industry code	28. Manufacture of machinery and equipment	30. Manufacture of other transport equipment	31. Manufacture of furniture
Type of collaboration with focal university	Industrial PostDoc	Collaborative research project	Collaborative research project
Number of employees	100 approx	80	25
R&D department	Yes	Yes	Yes
Year of establishment	1917	2002	1990

Table 3.1 Characteristics non-metropolitan cases (final)

	PT1 NM	PT2 NM	NO1 NM	NO2 NM
Main activity at the focal firm	Manufacture of fabricated metal products	Manufacture of refrigerators for restaurants, hotels and supermarkets	Machinery manufacturer for oil&gas operators	Machinery manufacturer for oil&gas operators
Nace industry code	25. Manufacture of fabricated metal products, except machinery and equipment	28. Manufacture of machinery and equipment n.e.c.	25. Manufacture of fabricated metal products, except machinery and equipment	28. Manufacture of machinery and equipment n.e.c. (Partner firm: 09. Mining support service activities)
Type of collaboration with the focal university	Collaborative research project	Collaborative research project	Industrial PhD	Collaborative research project
Number of employees	420-430 (200-250 beginning links with UA)	220-230	10	28
R&D department	No	Yes	Yes	No
Year of establishment	1965	1995	1986	2010

The following analysis of the case studies will begin with a discussion of the actions that facilitated the initiation of relations between the case firms and universities. This will be followed by an analysis of how these relationships unfolded over time. The cross-case comparison will uncover how the factors mentioned in section 5.3.2 influenced the initiation and unfolding of the relationships between the case firms and universities.

Table 3.2 Characteristics metropolitan cases				
	DK4 M	**DK5 M**	**PT3 M**	**NO3 M**
Main activity at the focal firm	Manufacturing of water quality sensors for fish farming	Machinery manufacturer for the food industry	Consultancy specialised on hydraulic engineering	Manufacturer of water treatment equipment
Nace industry code	26. Manufacture of computer, electronic and optical products	28. Manufacture of machinery and equipment n.e.c.	71. Architectural and engineering activities; technical testing and analysis	46. Wholesale trade, except of motor vehicles and motorcycles
Type of collaboration with the focal	Collaborative research project	Industrial PostDoc	Collaborative research project	Collaborative research project
Number of employees	50-53	380 (150 beginning links with DTU)	56	230
R&D department	Yes	Yes	Yes	Yes
Year of establishment	1987	1987	1996	Mid 1990s

5.6.2. PROCESSES FACILITATING THE START OF INDUSTRY–UNIVERSITY RELATIONS

A pattern emerged among four of the seven non-metropolitan cases, where the firms had been approached through outreach activities organised by the focal university (see Table A2.1 in the Appendix). In DK1 NM and PT2 NM, it was a researcher from the focal university who had approached the firm. In PT2 NM, researchers from the University of Aveiro were developing research on new refrigeration technology and needed a private partner that could help them with practical tests. Information from students who had carried out projects with the firm suggested that the firm had the competencies required to take part in the tests, since it had been conducting research on conventional refrigeration technology. After this first contact, the firm signed a support letter to help the university obtain the necessary funds to develop a research centre devoted to refrigeration technology.

Researcher PT2 NM: "We contacted the enterprise [in 2008] to see if they were interested in going ahead with [...] development work on this new technology. That's true that they are working [...] with the conventional technology. [...] We had some previous contacts, as some of our students were doing their projects with them."

In DK2 NM and PT1 NM, the contact started because managers from the focal firm participated in an event organised by the focal university. At one of these events (PT1 NM), the managers from the focal firm became acquainted with the manager of the University of Aveiro's technology transfer office. This manager would, in turn, facilitate approaching researchers from the mechanical engineering department. After this first contact, the firm would approach these researchers for consultancy projects, such as the development of a piece of aluminium for a German manufacturing multinational corporation (MNC)(see table A4.1 in the Appendix).

CEO PT1: "In 2009, I was at the first session on university–industry collaboration. This was promoted by the Portuguese SME Institute and the University of Aveiro, where we got to know the University of Aveiro and its technology transfer office. [...] With the director of the technology transfer office, we felt there was there a department […] that could interact with the industry."

This pattern differs from that of the metropolitan cases, where university actors did not approach the firms directly in any of the studied cases. In these cases, the first contacts occurred either because managers from the focal firm approached the university or because third-party organisations connected the focal firms with university researchers. In the case of DK5 M, the firm had approached the university as part of its employee recruitment strategy. In other cases, the initial link between the focal firm and focal university had occurred by participating in activities organised by a third party, such as taking part in a research project application made by another organisation (PT3 M) or a sectoral conference (NO3 M). For more information on the metropolitan cases, see Table A2.2 in the Appendix.

Thus, the cross-case comparison suggests that in non-metropolitan regions, actions undertaken by actors from the local university might play a key role in establishing links with firms. These first contacts can be initiated because the focal university invites firms to events aimed at establishing such links but also because researchers from the focal university approach the firm in search of suitable research partners or clients for commissioned research. Therefore, the findings point to actions through which universities could forge relationships with firms in non-metropolitan regions.

It should also be noted that among four of the seven non-metropolitan cases (DK1 NM, NO1 NM, PT1 NM and PT2 NM), university students tended to play a role in initiating the relationship between the focal firm and university (see Table A2.1 in the Appendix). In PT2 NM, students from the University of Aveiro provided to the university' researchers insights on research activities conducted at the firm where they

had participated in an internship. DK2 NM helped CTO DK2 NM develop their master's (2007) and doctoral projects (2008–2010) as an Aalborg University student by helping them build a chair for experimental research at the university, after an employee from that firm had met CTO DK2 NM at an event organised by Aalborg University in 2007. According to CTO DK2 NM, the firm wanted to learn about their knowledge by supporting their master's and doctoral projects. In 2015, the firm hired them as its new CTO.

CTO DK2 NM: "That was back in 2007... during my master's thesis, where I had some collaboration with them. I met a guy from [firm where they are currently employed] at a presentation we both attended [at the university]. [...] They helped me build a wheelchair for some experimental studies at the university."

Thus, the proactive role that non-metropolitan universities appear to play at the start of industry–university relations cannot be completely disentangled from the connections made by students from the focal university. Student projects provide an opportunity for initiating industry–university links, which might evolve later on into collaborative research.

5.6.3. UNFOLDING OF THE RELATIONSHIP BETWEEN THE FOCAL FIRM AND FOCAL UNIVERSITY

Among five of the seven non-metropolitan cases, the transitions to collaborative research were aided by governmental support schemes. In PT1 NM and PT2 NM, Horizon 2020 (H2020) funds from the EU helped the firms launch collaborative research projects with the University of Aveiro. PT2 NM's first links with the University of Aveiro, starting in 2008, were of an informal nature, with the firm providing a support letter for a research project application submitted by university researchers. In 2016, H2020 funds helped the firm implement research projects involving joint R&D work with the University of Aveiro.

Innovation director PT2 NM: "I knew there were H2020 incentives to do small research projects. [...] They were projects of 15,000–20,000 euros that could be materialised in one year, and we started there in December 2016 with the team we have now."

Among the other non-metropolitan cases (DK1 NM, DK3 NM and NO1 NM), national funding sources supported the transition to collaborative research. NO1 NM began its relationship with the University of Stavanger in 2011 by hosting student projects; students helped the firm solve technical problems posed by customers on product performance. In 2017, the firm's CEO proposed that the firm's CTO pursue

an industrial PhD at the University of Stavanger and apply for national funds to finance the industrial PhD.

CTO NO1 NM: "So, I got the contact of [researcher NO1 NM] at the time I started, so I went to the university. [...] [In 2017] my boss came to me. I think [my boss] had had a meeting at Innovation Norway and learned that it was possible to do an industrial PhD."

Thus, among the non-metropolitan cases, firm–university links evolved from non-collaborative relationships, such as human resource transfer and commissioned research activities, to collaborative research, where both parties supplied R&D work (Perkmann and Walsh, 2007). While this collaborative research took the form of industrial PhDs in some cases, in others, the firms became involved in research projects. In addition, cross-country differences are visible in the type of public funding sources that firms could obtain, with EU H2020 funds supporting collaborative research among the Portuguese non-metropolitan cases and national funding sources being more common in the Scandinavian cases. That national funds supported the transition to collaborative research in the Danish and Norwegian cases, but not in the metropolitan cases, might be related to the greater abundance of national public funds supporting industry–university relations in Denmark and Norway. However, it should be noted that EU structural funds have been relevant in supporting innovation projects in North Denmark (Growth Forum North Denmark, 2016).

The pattern among the non-metropolitan cases is similar to that of the metropolitan cases. In two out of four metropolitan cases, relationships between the focal firms and universities tended to start as publicly funded collaborative research (PT3 M and NO3 M), as shown in Table A3.2 in the Appendix.

5.6.4. ROLE OF ORGANISATIONS OTHER THAN UNIVERSITIES

Among five of the seven non-metropolitan cases (DK1 NM, PT1 NM, PT2 NM, NO1 NM, NO2 NM; see Table A4.1 in the Appendix), becoming more attractive to international customers appears to be a reason for the unfolding of industry–university relations into collaborative research. As in PT2 NM, customers demand new or improved products; this, in turn, incentivises the firm to increase its product development capabilities, generating greater interest in the firm in industry–university collaboration.

Innovation director PT2 NM: "[In energy efficiency] We started with Denmark, Norway, Sweden... [in 2009] they wanted to risk, and many are still with us. [...] We managed in 2011 that our biggest client [...] shifted to energy efficiency. [...] [The current project with the University of Aveiro] has brought many ideas that are being

applied to the products, and we have managed to reduce energy consumption a lot, which puts us at the level of the great European producers."

In other cases, like NO1 NM or NO2 NM, the focal firm had to offer products to international customers of sufficiently credible technical standards, and collaboration with university researchers helped the firm assess via scientific research the credibility of the product or develop technical expertise through an industrial PhD.

CTO NO1 NM: "From my boss' part, when they looked at it [the industrial PhD] for first time, I think they saw the opportunity to go in depth into the technical issues, because if we want to expand in the world, we need a stronger technical background. […] And that's also what we see when we go especially to Germany, maybe Holland too."

Among the metropolitan cases, pressure from international competitors incentivised the firms to engage in collaboration with universities. In DK4 M and DK5 M, competition from large foreign firms incentivised the firms to increase their research capabilities, turning human resource transfer links between these firms and the focal universities into collaborative research. Therefore, the metropolitan case firms also appear to have transferred their relationships with universities to collaborative research in order to be attractive to international customers (see Table A4.2 in the Appendix for details).

5.6.5. NON-METROPOLITAN FIRMS WITH R&D DEPARTMENTS

As mentioned in section 5.6.1, five out of seven non-metropolitan case firms had R&D departments when the interviews were conducted. During the interviews, it was reported that some of these firms (DK1 NM and PT2 NM) had already had R&D departments when the relationship with the case university started. As shown in Tables A4.1 and A5.1 in the Appendix, R&D departments appear to have contributed to the unfolding of the relationships between the non-metropolitan case firms and universities. In DK1 NM, being desirable to international customers had incentivised the firm to invest in research, and to separate the R&D department from the project department. The same goal, in turn, incentivised the firm to enhance its relationship with universities to full-fledged collaborative research.

Industrial PHD DK1 NM: "Now they have separated the project and research department, so projects are now focusing on delivering projects, and the research department is focusing on research. […] New regulations mean that customers have problems with the engines. How can we cope with the problems? And can we be better than the competitors? So, in that sense, you can also say that the customers drive the research."

In DK2 NM, one of the stated goals for the hiring of an R&D manager was to "*intensify [DK2 NM] cooperation with educational institutions*" (Press clipping, DK2 NM). And in NO1 NM, the firm had invested increasing resources in R&D along with the unfolding of its relationship with the University of Stavanger. Indeed, through the industrial PhD, the firm's CTO was able to increase their skills, and the contribution of the R&D department to the firm's innovation strategy.

Thus, the findings indicate that the absorptive capacity that R&D departments provide (Laursen and Salter, 2004) played a role in the unfolding of collaborations between the non-metropolitan case firms and universities. The R&D departments enhanced the non-metropolitan case firms' ability to develop new products and be attractive to international customers. At the same time, the R&D departments helped the firms integrate university knowledge, and the evidence suggests that the non-metropolitan case firms invested increasing resources in their R&D departments while they increased their collaboration with their university partners.

5.7. DISCUSSION

This paper builds on previous research by the author and other researchers (Drejer and Østergaard, 2017; Guerrero, 2020a, 2020b; Guerrero and Evers, 2018; Laursen and Salter, 2004; Mohnen and Hoareau, 2003) on what characteristics are positively associated with industry–university collaboration. This section discusses a set of propositions based on the case study findings and employs these propositions to develop a model of factors that can influence the initiation and unfolding of industry–university collaborations in non-metropolitan regions (Figure 1). In principle, the case selection strategy limits the transferability of the findings to larger firms and firms from sectors that traditionally have not relied on university research.

First, the case study findings relate to the characteristics of the focal non-metropolitan universities. Non-metropolitan universities have a strong propensity to cultivate links with regional firms through their educational and research activities (Alpaydin et al., 2018; Fonseca and Çinar, 2017; Guerrero and Evers, 2018; Nilsson, 2006; Rodrigues and Teles, 2017) and, as shown in the case studies, the outreach actions taken by these universities have led to the start of relationships with the case firms. Outreach actions might include events organised by the management of the focal university to promote industry–university collaboration but also actions taken by researchers from the focal university, such as searching for potential collaboration partners in the private sector. Thus, a first proposition can be formulated:

Proposition 1.1: Industry–university collaboration in non-metropolitan regions is likely to be initiated through the university reaching out to firms.

Second, the proactive role that non-metropolitan universities appear to play in the initiation of industry–university links cannot be completely disentangled from the connections established by students from the focal university. When seeking potential collaboration partners, researchers from non-metropolitan universities can tap into the information provided by university students on the firms where they have completed internships. Students can also be the first contact that initiates relationships between firms and universities, as they solve through their projects technical challenges that a firm faces or receive support from the firm in their student projects. The educational actions taken by non-metropolitan universities, thus, appear to provide a first, accessible contact point between firms and non-metropolitan universities, which allows the relationship to unfold. This observation corresponds to previous research findings that underlined the relevance of non-metropolitan universities' educational activities for establishing industry–university collaboration (Guerrero and Evers, 2018; Nilsson, 2006). Therefore, a proposition subsidiary to the first proposition can be formulated:

Proposition 1.2: In non-metropolitan regions, university students can help university actors approach non-metropolitan firms through internships or projects undertaken at the firms.

By suggesting that universities' actions are key to initiating industry–university relations in non-metropolitan regions, the model adds to previous research indicating that universities in non-metropolitan regions can be key innovation partners in these regions by committing their educational and research activities to supporting innovation in the regional business community (Alpaydin et al., 2018; Boucher et al., 2003; Evers, 2019; Fonseca and Çinar, 2017; Guerrero and Evers, 2018; Rodrigues and Teles, 2017). The findings also support the view that the characteristics of universities matter because the universities that carried out these actions are higher education institutions with a long track record of promoting industry–university links with firms in the region (Alpaydin et al., 2018; Fonseca and Çinar, 2017; Guerrero and Evers, 2018).

Third, the case study findings suggest that governmental support schemes (national in the Danish and Norwegian cases and coming from the EU H2020 programme among the Portuguese cases) appear to support the unfolding of relationships between non-metropolitan firms and universities directed towards collaborative research. This might be so due to the R&D work investments required to expand university–firm links from non-collaborative to collaborative relationships (Perkmann and Walsh, 2007). For these firms, collaborative research with universities might demand R&D investments beyond the firms' financial resources (Bruneel et al., 2016), unless public funding can compensate for the investments that firms must make. The analysis provides insights about the stages at which governmental support schemes become relevant in the non-metropolitan cases. Thus, the model adds substance to the finding that firms that have access to government support schemes are more likely to

collaborate with universities (Mohnen and Hoareau, 2003; Segarra-Blasco and Arauzo-Carod, 2008), leading to the second proposition:

Proposition 2: Public funds support the unfolding of industry–university links into collaborative research.

Fourth, previous research pointed out that collaboration with extra-regional organisations is positively associated with innovation among firms in non-metropolitan regions (Drejer and Vinding, 2007; Fitjar and Rodríguez-Pose, 2011; Grillitsch and Nilsson, 2015; Jakobsen and Lorentzen, 2015). In the case studies, interactions with international customers (whether foreign or home-grown MNCs) appear to play a role in non-metropolitan firms' innovative practices. Contrary to the literature, however, these interactions do not involve collaborating with international customers; rather, interactions with international customers tend to occur at an arm's length, with the non-metropolitan case firms unfolding their relations with universities in order to be attractive to potential or actual international customers. Thus, a third proposition is suggested:

Proposition 3: Non-metropolitan firms are incentivised to unfold their links with universities into collaborative research in order to be attractive to international customers.

Fifth, the non-metropolitan case firms tend to invest increasingly in R&D along the unfolding of the collaboration with the case university despite being firms that operate in sectors where R&D investments would not be expected to be key to innovation (Pavitt, 1984). While R&D helps the non-metropolitan case firms integrate knowledge from their university partners and develop products that are attractive to international customers, these firms appear to invest increasingly in R&D in order to further benefit from the knowledge generated by their university partners. The result is a co-evolutionary process between increasing investments in R&D and the unfolding of industry–university collaborations, adding substance to the insight that firms that have R&D departments are more likely to collaborate with universities (Laursen and Salter, 2004). Therefore, the final proposition can be formulated:

Proposition 4: R&D departments help non-metropolitan firms integrate university knowledge, supporting the firms' ability to attract international customers and collaborate with universities.

Thus, the model depicts a process in which the willingness to develop products attractive internationally and the support received from public subsidies incentivises non-metropolitan firms to unfold their links with universities into collaborative research. R&D helps non-metropolitan firms integrate university knowledge, further supporting the unfolding of industry–university links. Further, developing their R&D capacity better prepares the focal firms to absorb the knowledge generated by their

university partners, which supports the continuation and unfolding of their relationships with the case universities.

5.8. CONCLUSION

The present study aimed to contribute to the industry–university collaboration literature by advancing a set of propositions suggesting how factors that the literature has identified as being positively associated with industry–university collaboration might relate to the initiation and unfolding of collaborations between firms and universities in non-metropolitan regions. The model formulated in Figure 1 brings these propositions together:

Proposition 1.1: Industry–university collaborations in non-metropolitan regions are likely to be initiated through the university reaching out to firms.

Proposition 1.2: In non-metropolitan regions, university students can help university actors approach non-metropolitan firms through internships or projects undertaken at the firms.

Proposition 2: Public funds support the unfolding of industry–university links into collaborative research.

Proposition 3: Non-metropolitan firms are incentivised to unfold their links with universities into collaborative research in order to be attractive to international customers.

Proposition 4: R&D departments help non-metropolitan firms integrate university knowledge, supporting the firms' ability to attract international customers and collaborate with universities.

By virtue of their size and sectoral characteristics, the non-metropolitan case firms possess traits that are common to firms in non-metropolitan regions (Jauhiainen and Moilanen, 2012; Tödtling and Trippl, 2005, 2015). Thus, the case firms presented an interesting choice for a case study which was aimed at providing a deeper understanding of how industry–university collaboration starts and unfolds in non-metropolitan regions. Conversely, the findings of this study are not necessarily transferable to larger firms and/or firms operating in sectors where innovation is more likely to be based on university research. Future research could explore how similar the processes are among the latter firms.

Another limitation stems from the possibility that firms doing collaborative research with universities possess traits that make them particularly likely to forge such links.

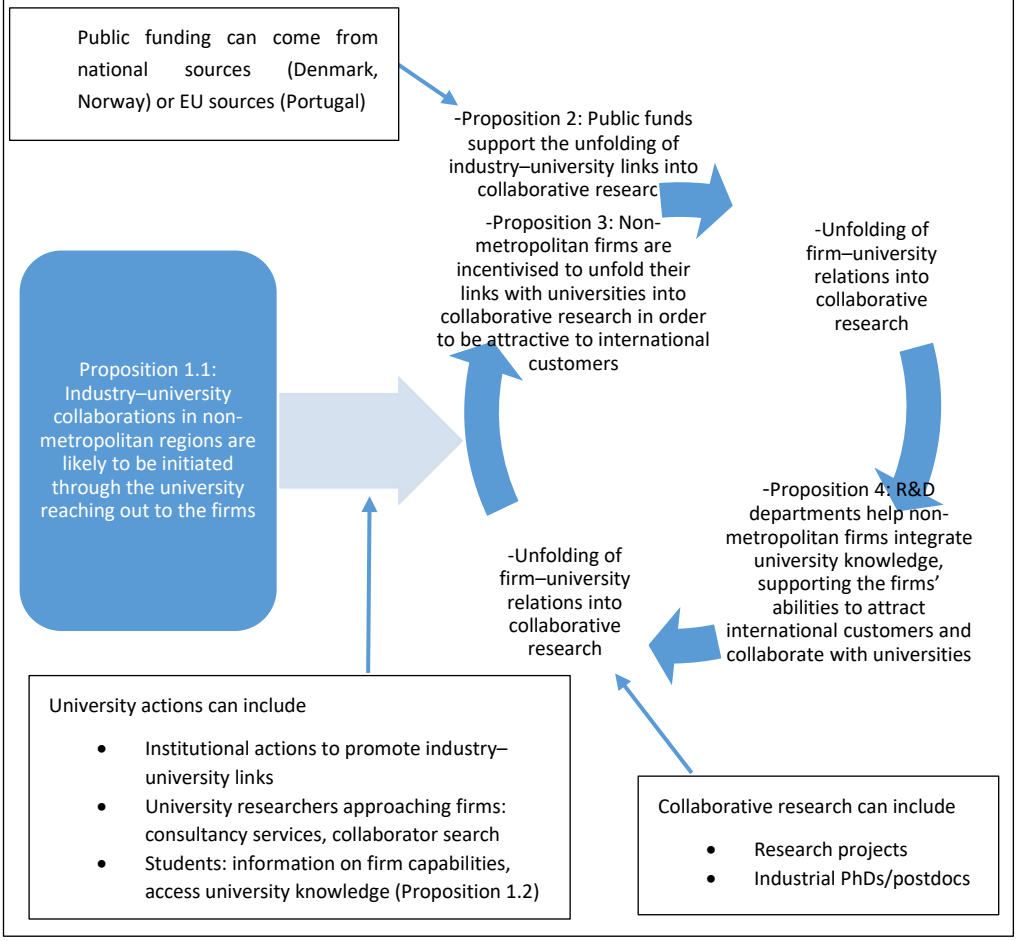
Thus, the present study could be extended with cases where the focal firm had an experience of collaborative research with universities but no longer engages in such partnerships or cases where the industry–university link of interest does not demand that the firm perform R&D work, such as contract research.

Similarly, the focal firms have collaborated with universities that have a strong propensity to interact with regional firms (Alpaydin et al., 2018; Fonseca and Çinar, 2017; Guerrero and Evers, 2018). It might be worth exploring how industry–university collaborations start and unfold in non-metropolitan regions where the focal university does not have a strong regional orientation.

Finally, managers at the universities of Aveiro, Stavanger and Aalborg contacted in the present study could not provide access to firms in metropolitan regions, except for the case study in the Lisbon metropolitan area. Thus, the author had to perform searches to locate and approach firms in metropolitan regions (see section 5.4.1). Approaching metropolitan firms proved considerably more difficult, resulting in the inclusion of a smaller number of metropolitan cases, and firms from sectors where university research might play a relatively important role, relative to non-metropolitan firms. Future research should tap into collaborative research with researchers located in metropolitan universities to approach metropolitan firms.

Despite these limitations, the findings from the case studies provide the literature with a model of factors that can influence the initiation and unfolding of industry–university collaboration in non-metropolitan regions. Furthermore, from a policy perspective, these findings suggest that it might be possible to extend the variety of firms with which non-metropolitan universities collaborate by incentivising these universities to dedicate more resources to approaching regional firms. Policymakers should also consider measures such as increasing the funding available to incentivise research collaboration between SMEs and universities and promoting the involvement of SMEs in international value chains.

Figure 1: Model of factors that can influence the initiation and unfolding of industry–university collaboration in non-metropolitan regions



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Appendix

Interview guide: Firm managers

Explanatory text for interviewees (company managers involved in innovation collaboration)

The purpose of this interview is to know how your firm got in contact with University XXXX [Stavanger, Aalborg, Aveiro], the reasons behind the start of this collaboration and how the collaboration unfolded over time. Previous research has observed that firms in sectors like yours are less likely to collaborate with universities compared to sectors like biotechnology. Such research has also suggested that the ways in which industry–university collaboration starts and unfolds might vary depending on whether firms are located in less densely populated regions or more densely populated regions.

Taking this research into account, I intend to compare this interview with interviews in firms in your sector or in sectors like yours, some of them in your region and others in other regions in Norway, Portugal and Denmark. The goal is to compare what leads firms to collaborate with universities and what leads this collaboration to unfold over time in regions without large metropolitan areas as well as regions with large metropolitan areas. With this goal in mind, the questions will focus on the following:

1. Characteristics of the company: main activities, product development, work organisation

2. How the current collaboration between the firm and the university began

3. Previous collaborations between the firm and the university or other universities; how they started

4. Collaboration with partners other than universities, like suppliers or customers; how they relate to the collaboration with the university

The answers that you kindly provide will be extremely useful in informing this research project and policies that can help firms like yours collaborate with universities and make the most of their collaboration with those universities. In return for your collaboration, we will send you a copy of the final project report. Thank you very much for your collaboration.

1. Interviewee position at the company

1.1. Could you describe your role at the company?

1.1.1. What is your background?

2. Information about the company

2.1. What are the main activities of the company?

2.1.1. Has the company changed the way it carries out its activities? →If yes, how so?

2.1.2. How does the company develop new products?

2.1.2.1. NOTE: The question can be shifted to "How does the company improve its production processes/ways of organising work responsibilities?" depending on the answer provided in 2.1.

3. Initiation and unfolding of industry–university collaboration

3.1. Now I would like to ask you about the company's collaboration with the university. What is the company doing with the university?

3.2. What are the goals of this collaboration?

3.2.1. How does the collaboration help the firm develop new products?

3.2.1.1. NOTE: The question can be shifted to "How does the collaboration help the firm improve its production processes/ways of organising work responsibilities and decision making?" depending on the goals formulated by the interviewee.

3.2.2. How did the collaboration start?

3.2.2.1. Possible probes depending on the interviewee's answer:

- When did the collaboration start?
- Who approached whom first – the company or the university?
- Who helped in connecting the firm with the university?→ How so?
- Were there any relations between the firm and the university before the collaboration started? → What kind of relations?
- What was happening at the company that might have facilitated the collaboration?
- Did driving time between the firm and the university play any role in the initiation of the collaboration? →What role did it play?
- Were there any challenges that posed an obstacle to further collaboration between your company and the university? → How did the company handle these challenges?

3.2.3. Is the collaboration between the firm and the university different now compared to when it started?

3.2.3.1. Probe depending on the interviewee's answer:

- In what ways is the collaboration different now compared to when it started?
- What has made the collaboration change?
- Has driving time between the firm and the university played any role in the evolution of the relationship since it started? →What role has it played?

3.2.4. Probe if this did not emerge in 3.2.2: "When was the first time the firm collaborated with a university?"

3.2.4.1. NOTE: If this is not the first time that the firm has collaborated with a university, the same question as 3.2.2. should be asked. Ultimately, the goal should be to probe until there is clarity on which processes led the firm to the first experience of industry–

university collaboration. If the interviewee is not knowledgeable about earlier experiences of collaboration with universities, ask him/her to help me approach an interviewee at the company who can provide this information.

4. Role of other organisations in firms' engagement in industry–university collaboration

4.1. On a related note, does your company collaborate with organisations other than the university?

4.1.1. Probe if the answer is affirmative:

- What are these organisations? →Do these organisations include research and technology organisations other than universities?
- What are the goals of these collaborations? →How do they help the company develop new products/improve production processes/improve ways of organising work?

4.2. Have other organisations made collaboration with the university more likely?

4.2.1. Probe if the answer is affirmative:

- Which organisations have made collaboration with the university more likely? →How so? →Can you give examples of how they have contributed?

5. Future evolution of industry–university collaboration/closure questions

5.1. Do you expect the firm to engage in further collaboration projects with this university or other universities? →With what goals in mind?

Interview guide: University researchers

Explanatory text for interviewees (researchers involved in collaboration with the focal firm)

The purpose of this interview is to understand what made the firm that you are collaborating with interested in collaborating with University XXXX [Stavanger, Aalborg, Aveiro]. With this goal in mind, the insights from this interview will be combined with those from managers at the firm that you are collaborating with.

Furthermore, I aim to compare the insights from the interviews with you and the company managers with those from interviews with other university researchers and company managers, covering the experiences of industry–university collaboration in other regions of Norway, Portugal and Denmark. The goal of these comparisons is to obtain insights into what makes firms in regions that are less densely populated collaborate with universities, compared to firms in regions that are more densely populated. With this goal in mind, the questions will focus on the following aspects:

1. How the current collaboration between the firm and the university began

2. Previous collaborations between the firm and the university or other universities; how they started

The answers that you kindly provide will be extremely useful in informing this research project and policies supporting high-quality collaboration between universities and firms. In return for your collaboration, we will send you a copy of the final project report. Thank you very much for your collaboration.

1. Interviewee position at the university

1.1. Could you describe your role at the university?

1.1.1. What is your background?

2. Processes behind industry–university collaboration

2.1. Now I would like to ask you about your collaboration with company XX. What is the collaboration with company XX about?

2.2. What are the goals of this collaboration?

2.2.1. How does the collaboration help the firm develop new products?

2.2.1.1. NOTE: The question can be shifted to "How does the collaboration help the firm improve its production processes/ways of organising work responsibilities and decision making?"

2.2.2. How did the collaboration start?

2.2.2.1. Possible probes depending on the interviewee's answer:

- When did the collaboration start?
- Who approached whom first – the company or the university?
- Who helped in connecting the firm with the university?→ How so?
- Were there any relations between the firm and the university before the start of the collaboration? → What kind of relations?
- What was going on at the company that might have made the collaboration more likely?
- Were there any challenges that posed an obstacle to further collaboration between the company and the university? → How did the company handle these challenges?

2.2.3. Is the collaboration between the firm and the university different now compared to when it started?

2.2.3.1. Probe depending on the interviewee's answer:

- In what ways is the collaboration different now compared to when it started?
- What has made the collaboration change?

2.2.4. Probe if this did not emerge in 2.2.2: "Was this the first time the firm had collaborated with a university?"→If not, the same question as 2.2.2. should be asked. Ultimately, the goal should be to probe until it becomes clear which processes led the firm to the first experience of industry–university collaboration. If the interviewee is not knowledgeable about earlier experiences of collaboration with universities, I should ask him/her to help me approach another researcher who can provide this information.

3. Evolution of industry–university collaboration/closure questions

3.1. Do you expect the firm to engage in further collaboration projects with this university or other universities? →With what goals in mind?

Table A1. NACE Rev. 2 sectoral codes excluded from the case selection (Source: Drejer and Østergaard, 2015, p. 15)
High-tech manufacturing codes
21: Manufacture of basic pharmaceutical products and pharmaceutical preparations
26: Manufacture of computer, electronic and optical products
Knowledge-intensive service codes
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, management consultancy activities
71: Architectural and engineering activities, 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, 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

Table A2.1 What initiated relations with the focal university, non-metropolitan cases		
Case	**How it started**	
DK1 NM	University consultant approached firm. University student internships	Industrial PhD DK1 NM: "*So, the [Aalborg University] consultant's job was to do some development, but not research collaborations as industrial PhD or another project. […] It was [him/her] who approached the company. […] We also had a couple of projects where there was a student worker.*"
DK2 NM	Event at Aalborg University. Firm became acquainted with the interviewee, future CTO	CTO DK2 NM: "*That was back in 2007... during my master's thesis, where I had some collaboration with them. I met a guy from [firm where they are currently employed] at a presentation we both attended [at the university]. […] They helped me build a wheelchair for some experimental studies at the university.*"
DK3 NM	The firm approached the university through business networks	Owner DK3 NM: "*I have been in different networks. […] And so they almost always said that there is this department at Aalborg University. […] 15 years ago, a bit more, we began […] That was in fact one student […] that helped with the first materials we had in English and had some contact with England, and we had EU support funds.*"
PT1 NM	Firm invited to event organised by Portuguese SME institute and Aveiro University	CEO PT1 NM: "*In 2009, I was at the first session on university–industry collaboration. This was promoted by the Portuguese SME Institute and the University of Aveiro, where we got to know the University of Aveiro and its technology transfer office.*" [Later on, the company approached the university for consultancy services and hosted student internships].
PT2 NM	Researchers from the University of Aveiro approached the firm. Previous student contacts	Researcher PT2 NM: "*We contacted the enterprise [in 2008] to see if they were interested in going ahead with […] development work on this new technology. That's true that they are working […] with the conventional technology. […] We had some previous contacts, as some of our students were doing their projects with them.*"
NO1 NM	Firm approached University of Stavanger researcher because of customers' questions	Researcher NO1 NM: "*[former CTO] contacted me [in 2011] because they wanted to have some understanding of the [product] mechanics. And their customers came up with questions. […] Then I just mentioned [to the company] […] it is too late for a Bachelor project or master's project, but I have a semester project within a couple of months.*"
NO2 NM	Firm approached University of Stavanger researcher because of customers' questions	The firm approached the university in search of consultancy services. CEO NO2 NM: "*A customer asked if we had a solution... if it's possible to do something with the [pipeline] pressure." / Managing director partner NO2 NM: "I didn't have the background from the multiphase flowing [needed for a client]. […] I was googling multiphase flowing and [University of Stavanger researcher] came up.*"

Table A2.2 What initiated relations with the focal university, metropolitan cases		
Case	**How it started**	
DK4 M	Student internships, starting with the current CEO. Unclear who approached whom	CEO DK4 M: "*The first [intern] was in 1996, because that was when I started [laughs]. [...] I think the idea was that it is easier than if you want to hire an engineer; it is easier to have him for half a year because it is easier to see if he is good.*"
DK5 M	Firm approached universities to create a reputation and attract candidates	CEO DK5 M: "*In 2007 or something, I said, 'I want the companies to say yes to every student who wants help [in a training position]'." / COO DK5 M: "We were also in a situation with this closeness, or whatever you want to call it, and our name not being known for what it stands for... when we had to do recruitment, we were competing a with Siemens, Carlsberg.*"
PT3 M	Firm involved in third party–led research project application. Merged with another project application with focal university	Head water department PT3 M: "*The firm has been involved in [EU funded project] since 2013. [...] We were trying to start with another organisation, and on the other side there was the University of Évora and the institute. In Portugal, there were two projects pursuing the same idea, and we were told to join forces*."
NO3 M	Triggered by interviewee's presence at a sectoral conference. Third party encouraged the firm to approach the university	Innovation manager NO3 M: "*I was at a conference in March last year about fish farming. [...] One of the guys on that panel came from the Research Council of Norway… state organisation with lots of money… and said you should make a research program to find out all these other elements.*"

Table A3.1 Evolution of the relationship with the focal university, role of public funding, non-metropolitan cases		
Case	**Summary of changes**	
DK1 NM	Jump research partnership, supported by national public funding	Industrial PhD DK1 NM: "*So, I think one year before I started the PhD* [2014]*, I think in the northern region, they had this meeting on research in the northern area […] In this meeting, the CEO attended and was definitely interested in the industrial PhD programme. [...] So, as I defended my PhD, I went into this postdoc position [supported by public technology demonstration programme]*."
DK2 NM	Jump research partnership, not supported by public funding	CTO DK2 NM: "[Reasons for being hired as CTO in 2015] *my profile was not just Aalborg University; it was also that my research was within the area of the company's products. […] Er... public funding is difficult to get and takes a lot of time and it's not our focus*."
DK3 NM	Jump research partnership, supported by EU H2020 public funding	CEO DK3 NM: "*[Aalborg University researcher] has been work together with [owner DK3 NM]. […] [Aalborg University researcher] said, 'We have a project for you here. It's called [EU H2020 funded project]. It might be something for you'.*"
PT1 NM	Jump research partnership, supported by EU H2020 public funding	CEO PT1 NM: "*I had a candidacy for an H2020 project which could be interesting for us to have something with a university on research and innovation, and that this innovation led to the publication of an article, no? [...] We went to the University of Aveiro [...] It was about doing structural calculations of the resistance of windmill lifts.*"
PT2 NM	Jump research partnership, supported by EU H2020 public funding	Innovation director PT2 NM: "*I knew there were H2020 incentives to do small research projects. [...] They were projects of 15,000–20,000 euros that could be materialised in one year, and we started there in December 2016 with the team we have now*."
NO1 NM	Jump research partnership, supported by national public funding	CTO NO1 NM: "*So, I got the contact of [researcher NO1 NM] at the time I started, so I went to the university. [...] [In 2017] my boss came to me. I think [my boss] had a meeting at Innovation Norway and learned it was possible to do an industrial PhD.*"
NO2 NM	Jump research partnership, not supported by public funding	Managing director partner NO2 NM: "*So, what we are doing now is to show it in a theoretical model as well, because actually what comes from UiS has credibility amongst all the operator companies [...] then we can get funding for running a full-scale test." /*CEO NO2 NM: *"If we had bigger frames in economics, I think that we would have run the project totally different way.*"

Table A3.2 Evolution of the relationship with focal university, role of public funding, metropolitan cases

Case	Summary of changes	
DK4 M	Jump research partnership, supported by national public funding	CEO DK4 M: "*Then [2000], we had small projects, you can say, on the way, but mainly founded by the Danish government, where they wanted to make some connection between the university and the commercial partners.*"
DK5 M	Jump research partnership, supported by national public funding	The firm hosted a master's thesis student, who is currently an industrial postdoc, as part of its collaboration in NETWORK, an innovation network financed by Innovation Denmark. CEO DK5 M: "*[NETWORK] contacted us because they thought that it might have relevance for us to be a part of it. Because we are probably known as very innovation heavy. And we are industry.*"
PT3 M	Collaborative research project from the start, supported by EU non-H2020 public funding	Head water department PT3 M: "*In Portugal, there were three [EU non-H2020 fund programme] projects approved in 2013, and this was one of them.*"
NO3 M	Collaborative research project from the start, supported by national public funding	Innovation manager NO3 M: "*So, we put together a group of companies [and universities] that actually each have different competence, you know, and we made an application and we got a budget and this programme will run for 3.5 years.*"

Table A4.1 Relevance of relationships with organisations other than universities, non-metropolitan cases		
Case		
DK1 NM	Attractiveness to international customers	Industrial PhD DK1 NM: "*New regulations mean that customers have problems with the engines. How can we cope with the problems? And can we be better than the competitors? So, in that sense, you can also say that the customers drive research. […] So, the biggest companies are [foreign MNC competitors]. They are engine manufacturers. […] How can we be better than our competitors? […] And research is a big strategic factor there.*"
DK2 NM	Attractiveness to customers, unclear if international	CTO DK2 NM: "*Most companies go towards mass products and cheap chairs. […] Well, [DK2 NM] goes in the opposite direction: Make expensive chairs that are custom-made.*"
DK3 NM	Attractiveness to local customers	CEO DK3 NM: "*Mainly we are in the Danish market. About 80% of our turnover is going to the Danish market. We're in Sweden, Germany and France... But it's mainly Denmark... […] Our competitors… the largest of them also have a strength here [in the area of sustainability] but it is not at the same level as we are, to be honest.*"
PT1 NM	Attractiveness to international customers	CEO PT1 NM: "*When we were about to curve this piece [of aluminium, for a German MNC supplier in the automotive industry], we did a test and we saw that curving that piece would be very complicated. […] We contacted the University of Aveiro so that they could help us with the structural calculus to see how the piece would respond.*"
PT2 NM	Attractiveness to international customers	Innovation director PT2 NM: *"[In energy efficiency] We started with Denmark, Norway, Sweden... [in 2009] they wanted to risk, and many are still with us. […] We managed, in 2011, that our biggest client […] shifted to energy efficiency. […] [The current project with the University of Aveiro] has brought many ideas that are being applied to the products, and we have managed to reduce energy consumption a lot, which puts us at the level of the great European producers.*"
NO1 NM	Attractiveness to international customers	CTO NO1 NM: "*From my boss' part, when they looked at it [the industrial PhD] for first time, I think they saw the opportunity to go in depth into the technical issues, because if we want to expand in the world, we need a stronger technical background. […] And that's also what we see when we go especially to Germany, maybe Holland too.*"
NO2 NM	Attractiveness to international customers	CEO NO2 NM: "*It's a high cost when you go offshore and you test, so we need theoretical calculations and verifications that this is something doable.*" / Managing director NO2 NM: "*So, what we are doing now is to show it in a theoretical model as well, because actually what comes from UiS has credibility amongst all the operator companies […] then we can get funding for running a full-scale test.*"

Table A4.2 Relevance of relationships with organisations other than universities, metropolitan cases

Case		
DK4 M	Attractiveness to international customers	CEO DK4 M: "*We are in a niche, you could say, but the pressure is getting bigger. And that's why we made that decision many years ago to turn up on R&D so we're sure we could compete. [...] And then… in order to be able to compete with the Asians, we need to have an R&D department. We need to be ahead. [...] You can say when we link with DTU, KU or whatever, is to be able to find technologies of proof of concept [...] that this will work.*"
DK5 M	Attractiveness to international customers	CEO DK5 M: "*Primarily the big competitors are in Germany and Switzerland. And then there are some in Italy as well. [...] So, the reason many times that we are chosen as a supplier is because we can do the 20% [customised production] But we didn't have control over the 80% right. [...] Who can help us with that? And then we found out by coincidence actually that we had the NETWORK organisation.*" / COO DK5 M: "*It was through [NETWORK], but it started as a master's thesis and then it was later on... was handed over to be a postdoc project, which we are doing now.*"
PT3 M	Unknown	Head water department PT3 M: "*[PT3 M] is involved in [EU funded project] since 2013. [...] We were trying to start with another organisation [a civil society organisation], and on the other side there was the University of Évora and the institute. In Portugal, there were two projects pursuing the same idea, and we were told to join forces.*"
NO3 M	Attractiveness to international customers	Innovation manager NO3 M: "*In Scandinavia, we are probably the biggest private-owned water treatment company. We have a factory in Sweden and a factory in Norway. We have our own distribution in Germany. We used to have it in Denmark. [...] But a very important factor is that when it comes to water production and water treatment, it has to do with competence [in different areas].*"

Table A5.1 R&D among the non-metropolitan cases			
Case	**R&D department, initiation of collaboration with focal university**	**R&D department, currently**	
DK1 NM	Yes	Yes	Industrial PhD DK1 NM: "*What we did previously was okay: make a system, implement it in the engine, see how the engine reacts. […] Nowadays, we follow a more scientific path, where we do a model of how the lubrication affects the engine, how can we optimise that [...] Now they have separated the project and research departments, so projects are now focusing on delivering projects, and the research department is focusing on research.*"
DK2 NM	No	Yes	Press clipping DK2 NM: "*With the 1st of September [2015], [DK2 NM] welcomes a new staff member. As R&D Manager, [CTO DK2 NM] is supposed to strengthen our development division regarding consistent further development of existing and new products. [...] [CTO DK2 NM] will introduce a rather scientific approach to good sitting postures. They will furthermore intensify [DK2 NM] cooperation with educational institutions.*"
DK3 NM	Unknown	Yes	Unknown.
PT1 NM	No	No	CEO PT1: "*We do R&D inside [PT1 NM], probably the same or more than the university... but we don't call this R&D. It was about trying, correcting, trying again... okay? We don't call it R&D but it is.*"
PT2 NM	Yes	Yes	Innovation director PT2 NM: "*We can go back to 2005 […] we started doing this research with the University of Coimbra. We were almost two years doing research, very focused on energy efficiency. […] After that, we became more interested in research.*"
NO1 NM	Unknown	Yes	CEO NO1 NM: "*It was kind of a natural development in the scientific approach… We have several bachelors, masters… and it would be a natural development to go into the PhD to extend the knowledge.*"
NO2 NM	Unknown	Yes (formally. Role not salient at the practice)	CEO NO2 NM: "*We have someone that is officially responsible for R&D, but it's typical Norwegian, and we are even more typical. It's done in the day-to-day organisation.*"

Table A5.2 R&D among the metropolitan cases

Case	R&D department, initiation of collaboration with focal university	R&D department, currently	
DK4 M	Yes	Yes	CEO DK4 M: "*From the beginning, it was a bit different, and over the last 10 years, it has changed a lot. Maybe in the beginning, it was only 10% and today we are at least 30% [in R&D staff]. […] I would say we have a quite big engineering and research department. And we probably have 10 projects running at all times.*"
DK5 M	Yes	Yes	CEO DK5 M: "*So, actually the research and the innovation and the collaboration between [the company and the university] originates from way back. [...] long history of patents on the technology and machinery.*"
PT3 M	Yes	Yes	Head water department PT3 M: "*The relationships with universities grew [since 2011]; however, it was always more personal. All the years I teach at the university where I work [university other than the University of Évora]. [...] Personal relations always help in establishing contacts.*"
NO3 M	Yes	Yes	Innovation manager NO3 M: "*Before we started [NO3 M], we had a master's student doing half a year of thesis work, doing the big research like you are doing now. [...] This is how we [started the company]... and this was done by University of Stavanger.*"

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SUMMARY

Since the 1980s, policymakers have promoted universities' involvement in regional economic development. Increasingly since then, universities have been incentivised to develop a range of third-mission activities to transfer their knowledge to local firms, adapting their educational and research activities to support innovation in regional firms in the process. At the same time, increasing regional disparities in innovative activity and economic development suggest that policies promoting collaboration between universities and regional firms should be suited to different types of regions; factors that are relevant to industry–university collaboration in one type of region might not be as relevant in another type of region. Thus, the present thesis addresses the following research question: "To what extent do the roles of key factors associated with university–industry collaboration differ across types of regions?" This thesis includes four papers, which use quantitative and qualitative data for Denmark. One of the papers uses qualitative data for Denmark, Portugal and Norway.

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