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Scientist Mobility
Essays on Knowledge Production and Innovation

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Document Version
Final published version

Publication date:
2021

License
Unspecified

Citation for published version (APA):
Uhlbach, W.-H. (2021). *Scientist Mobility: Essays on Knowledge Production and Innovation*. Copenhagen Business School [Phd].

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Download date: 04. Jul. 2025

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DK-2000 FREDERIKSBERG
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WWW.CBS.DK

ISSN 0906-6934

Print ISBN: 978-87-7568-022-1
Online ISBN: 978-87-7568-023-8

SCIENTIST MOBILITY: ESSAYS ON KNOWLEDGE PRODUCTION AND INNOVATION

PhD Series 23.2021

Wolf-Hendrik Uhlbach

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Scientist Mobility

Essays on knowledge production and innovation

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Scientist Mobility: Essays on knowledge production and innovation

1st edition 2021
PhD Series 23.2021

© Wolf-Hendrik Uhlbach

ISSN 0906-6934

Print ISBN: 978-87-7568-022-1
Online ISBN: 978-87-7568-023-8

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Acknowledgements

After almost four years, a global pandemic and merely a year in lockdown, the PhD journey comes to an end. While much of the work has been conducted in solitude with the trusted companionship of the Danish data in all of its forms, this work would not have been possible without the support provided of many people and the vibrant environment within the SI-department and beyond.

First and foremost, I am hugely indebted to my two supervisors, Hans Christian Kongsted and Valentina Tartari. Without their continuous guidance and support from day one much of this work would not have been possible. Their patience and insights in showing me the various aspects of academia, while being excellent mentors, was of tremendous importance for my development and the intellectual journey over the past four years. It has been a great pleasure to work, learn and collaborate with both on the Triple-I project. Here I would also like to acknowledge the generous financial support by the project allowing me to visit various conferences and the support provided to my research more generally. Further, I also owe gratitude to my co-author Paul Anckaert, and the many discussions and productive collaboration throughout the past years.

I also like to thank Markus Simeth for his insightful and detailed comments on this thesis during the pre-defense, and his availability for discussions throughout the past years. I am also grateful to Mercedes Delgado for her comments during the pre-defense and chairing the assessment committee as well as Ina Ganguli and Matt Marx for joining Mercedes for my final defense.

A special thank you also goes to Scott Stern at MIT, for giving me the opportunity to spend a semester at MIT as a visiting Phd student, and the frequent and extremely developmental meetings which have enriched my thinking tremendously.

I would further like to thank Maryann Feldman for her great support, particularly during the job market. A special thanks also goes to Ron Boschma, David Rigby, Pierre-Alexandre Balland, Andrea Morrison, Tom Broekel, and Thomas Scherngell, for many great discussions and igniting my interest in following an academic career path.

In addition, I would also like to thank SI for being such a collegial department and supporting environment. In particular, I am grateful for advice, support and conversations with Christoph Grimpe, Karin Hoisl, Larissa Rabbiosi, Louise Mors, Madeleine Rauch, Mark Lorenzen, Michael Mol, Peter Lotz, Peter Maskell, Uli Kaiser, Toke Reichstein, Thomas Rønde, Vera Rocha, and Wolfgang Sofka (alphabetically ordered). A special thanks goes to Keld Laursen for his continued support and advice throughout the past four years, which have been of tremendous help and an important imprint on my academic thinking.

I am also thankful to my fellow PhD students, or those whom I have crossed path while I was a PhD student at SI for the many fun activities and friendships during a stressful time and demanding period: Adrian, Agnes, Alina, Alison, Carolyn, Diego, Hadar, Louise, Manar, Nathan, Rita, Sara, Selorm, Shleter, Tiare, and Theo.

Lastly, I would like to thank my family for their continued support throughout this journey and from the very start of my academic career. Here I would like to thank my parents, Heinrich and Christa-Renate, and my sister Domenica who have been a support throughout.

Summary

The mobility of workers is one of the most important channels through which knowledge is transferred across geographical and organizational boundaries. This mechanism is particularly important in early stages of knowledge production, where knowledge is not yet fully codified and still requires insights of the knowledge producers themselves to apply it to a commercial use. This thesis therefore investigates the effects of the mobility of two types of highly skilled workers on the rate and direction of innovation and research.

The first paper investigates the firm level consequences. It asks how hiring foreign R&D workers effects the type of firm level innovation. By differentiating between explorative and exploitative innovation, it finds that hiring foreign R&D workers is strongly associated with exploration, and therefore can shift a firm's inventive activities towards new technology fields. These effects hold, even after controlling for differences in education between newly hired foreign workers and incumbent workers, and are most pronounced when foreign workers are from countries that are new to the firm.

The second paper investigates the individual level consequences of international mobility in the context of academic entrepreneurship. While in this context, international mobility is commonly linked to higher levels of scientific productivity, little remains known about its effects on other aspects of academics' careers, such as academic entrepreneurship. By differentiating between different types of international mobility, the paper finds that internationally mobile native academics were more likely to start a company, whereas immigrant academics are about 38-47% less likely to start a company in Denmark compared to returnees. This difference suggests that there are substantial barriers to foreign academics' engagement in academic entrepreneurship.

The final paper investigates how academic entrepreneurship affects scientific knowledge production. Spanning the boundary between the academic and commercial sector, not only requires academic entrepreneurs to fulfil multiple roles at the same time, but also leads to the accumulation of skills and knowledge, likely to have long-term effects. This paper,

therefore focusses on two important outcomes – scientific productivity and collaboration, and investigates the immediate and long term effects of academic entrepreneurship. It finds, that academic entrepreneurship is associated to an immediate drop in scientific productivity, which persists immediately after the entrepreneurial spell, but attenuates in the long run. It further establishes a negative effect on repeated co-authorships, persisting in the long run. It therefore draws attention to potentially negative career effects academic entrepreneurs face when commercializing their research.

Resumé

Arbejdskraftmobilitet er en af de vigtigste kilder til at overføre viden påtværs af lande- og virksomhedsgrænser. Det er en særligt vigtig mekanisme i de tidlige faser af videnproduktionen, hvor viden ikke er fuldt ud systematiseret og stadig behøver videnproducenternes egen indsigt for at kunne overføres. Derfor undersøger denne afhandling effekten af to former for højtuddannet arbejdskraftmobilitet og indvirkningen pågraden og retningen af innovation og forskning.

Den første artikel undersøger konsekvenserne påvirksomhedsplan, og hvordan rekruttering af udenlandsk R&D -arbejdskraft påvirker innovation i virksomheder. Ved at skelne mellem undersøgende innovation og udnyttende innovation konstateres det i artiklen, at rekruttering af R&D- arbejdskraft er stærkt forbundet med undersøgende innovation og at virksomheder derfor kan rette deres innovation mod ny teknologi. Effekten varer ved, selv når man regulerer for den kognitive distance mellem nyansat udenlandsk arbejdskraft og allerede ansatte. Effekten er mest udtalt, når den udenlandske arbejdskraft kommer fra lande, virksomheden ikke har erfaring med.

Den anden artikel undersøger de individuelle effekter af international mobilitet i forbindelse med iværksætteri inden for forskningsverdenen. Selvom international mobilitet i denne sammenhæng sædvanligvis forbindes med højere akademisk produktivitet, ved man stadig ikke meget om, hvordan mobiliteten påvirker andre aspekter af forskerkarrieren, som fx iværksætteri. Ved at skelne mellem forskellige typer af international mobilitet konstateres det i artiklen, at indfødte forskere, der er internationalt mobile, har større sandsynlighed for at starte en virksomhed, hvorimod ikke-indfødte forskere har 38-47% mindre sandsynlighed for at starte virksomhed i Danmark sammenlignet med dem, der vender hjem. Denne forskel indikerer væsentlige barrierer for, at udenlandske forskere kan engagere sig i iværksætteri.

Den sidste artikel undersøger, hvordan iværksætteri blandt forskere påvirker den akademiske videnproduktion. At undersøge grænsefeltet mellem universitetsverdenen og det private erhvervsliv kræver ikke kun, at iværksættere skal udfylde mange roller påsamme tid, men

fører ogsåtil akkumulering af både viden og kompetencer, som sandsynligvis har langtidseffekt. Artiklen fokuserer derfor påto vigtige resultater – akademisk produktivitet og samarbejde mellem forskere. Endvidere undersøges både den umiddelbare og den langvarige effekt af iværksætteri inden for forskning. I artiklen konstateres det, at denne form for iværksætteri kan forbindes med et umiddelbart fald i produktiviteten, som er stabilt til umiddelbart efter iværksætterperioden, men derefter aftager pålangt sigt. Derudover påvises en negativ effekt pågentagent medforfatterskab, som varer ved pålangt sigt. Dermed skabes der opmærksomhed om en potentielt negativ effekt påforskernes karriere, hvis de ønsker at markedsføre deres forskning.

Contents

Introduction

The importance of basic scientific research and innovation to economic growth and development has long been recognized (Schumpeter, 1942; Romer, 1990; Mokyr et al., 2002; Nelson, 1959). Many groundbreaking innovations, such as DNA amplification and global positioning systems (GPS), take their origins at universities (Ahmadpoor & Jones, 2017; Murray, Aghion, Dewatripont, Kolev, & Stern, 2016). Also, firms view knowledge produced in academia as a source of competitive advantage. This importance has recently been quantified by Ahmadpoor and Jones (2017), who showed that around 61% of commercial innovations can be traced back to knowledge derived from academia, and Marx and Fuegi (2020) highlighted how firms rely on science.

The outcomes of basic scientific research are, however, of uncertain value, as they are not directly applicable to commercial problems, and knowledge of their use and creation are often tacit (Cowan, David, & Foray, 2000; Polanyi, 1962).To translate this type of knowledge, the importance of involving the knowledge producers themselves is often emphasized; therefore, a way through which such knowledge can be transferred across geographical and organizational boundaries is via the mobility of highly skilled individuals. This mobility has been shown to play an important role in the transfer of tacit and highly contextualized knowledge (Polanyi, 1962; Choudhury & Kim, 2019; Zucker & Darby, 1996). This, thesis focuses on two types of mobility of highly skilled workers and investigates its effects on the rate and direction of innovation and scientific research. The first type of mobility is the international mobility of scientists and engineers. The second type refers to the cross-sectoral mobility of academic scientists.

Over the past decades, the international mobility of scientists and engineers has steadily increased (Scellato, Franzoni, & Stephan, 2012). As cross-border mobility has become easier and information about opportunities are more widely accessible, an increasing number of individuals take up employment in countries, other than their home country (W. Kerr, 2018).

On the individual level, international mobility is commonly associated with superior productivity and higher levels of entrepreneurship. This is corroborated by a vast number of studies that show that internationally mobile scientists are more productive on average (Scellato et al., 2012), and are overrepresented among Nobel Prize winners (Hunt, 2010). Furthermore, in a non-academic setting, immigrants are overrepresented among inventors (Breschi & Lissoni, 2009) and among founders of high-tech companies (S. P. Kerr & Kerr, 2016).

While international mobility is argued to increase the flow of knowledge and exchange of ideas, its effects are difficult to evaluate independently from its motivations. Therefore, studies exploiting changes in the freedom to move and involuntary movements provide valuable insight into the effects of immigration and international mobility. In this line, immigration has been linked to the transfer of technological knowhow (Hornung, 2014) and the transfer of knowledge (Ganguli, 2015; Moser, Voena, & Waldinger, 2011; Choudhury & Kim, 2019), and, on a more aggregate level, to industry and technology specific shifts in patenting (Akcigit, Grigsby, & Nicholas, 2017; Bahar, Choudhury, & Rapoport, 2020; Morrison, Petralia, & Diodato, 2018).

The second type of mobility refers to the mobility between different types of organizations, commonly attributed to different sectors: universities and private firms (Allen, 1977; Dasgupta & David, 1994; Cohen, Sauermann, & Stephan, 2020). The main difference between these two *sectors* is commonly associated with the norms and incentives governing the production of knowledge. Academic scientists have shown to be motivated by intellectual freedom and disclosure of results (Merton, 1973), to the extent that they are even willing to give up higher salaries in order to achieve this (Stern, 2004).

Nonetheless, the boundaries between the two sectors are not as sharp as commonly believed (Dasgupta & David, 1994). Scientists do not always choose topics purely basesd on scientific potential, but are also directed by commercial incentives (Rosenberg, 1982), the availability of science-related funding (Myers, 2020; Evans, 2010; Goldfarb, 2008), and research conducted at local industries (Sohn, 2020). Some scientists also have strong preferences for commercialization and aim to benefit financially from their discoveries by starting companies themselves (Rothaermel, Agung, & Jiang, 2007; Perkmann et al., 2013).

Taken together, this type of mobility offers the potential to shape knowledge production in academia (Buenstorf, 2009; Toole & Czarnitzki, 2010; Fini, Perkmann, & Ross, 2021).

1.1 Thesis Structure

This thesis investigates how two types of mobility, international and cross-sectoral, of highly skilled workers affect the rate and direction of innovation and scientific research. Chapters 2 and 3 focus on the effects of international mobility. Chapters 3 and 4 focus on the cross-sectoral mobility of academics, spanning academia and entrepreneurship. Chapters 2 and 4 share the focus on how individual level experiences in different sectors or countries shape the production of knowledge. Overall, this thesis builds on uniquely comprehensive matched employer–employee data, which has been enhanced by patent applications and scientific publications, both at the individual as well as the organizational level, and detailed survey data of Danish academics. Table 1 contains a more detailed overview of the chapters, and the remainder of this section describes each chapter in more detail.

Table 1.1: Overview of the chapters

Title	Research Question	Unit of Analysis	Outcome	Data	Method
Chapter 2: In search of new knowledge: When does hiring foreign R&D workers foster exploration?	How does hiring foreign R&D workers affect firm-level exploration?	Firm level	Exploration	Survey and Publications	Discrete time hazard model
Chapter 3: Beyond scientific excellence: Are internationally mobile researchers more likely to become academic entrepreneurs?	What is the relationship between internationally mobile entrepreneurs	Individual level	Entrepre–neurial entry	IDA and Patent Applications	Count models and academic Difference-in-differences
Chapter 4: The effects of academic entrepreneurship on knowledge production and collaboration in academia	How does academic entrepreneurship affect the productivity and collaboration patterns of academic scientists both during and after entrepreneurial spells?	Individual level	Scientific productivity and repeated collaborations	IDA and Publications	OLS and Matching

1.1.1 Chapter 2: In search of new knowledge: When does hiring foreign R&D workers foster exploration?

Chapter 2 of this dissertation focuses on how hiring foreign R&D workers affects the types of firms' subsequent innovations. The inward mobility of highly skilled workers has long been acknowledged to foster knowledge spillovers between firms and affect innovation (Tzabbar, 2009; Agarwal, Ganco, & Ziedonis, 2009). A particular driver of this effect pertains to the characteristics of hired workers (Tzabbar, 2009; Bogers, Foss, & Lyngsie, 2018; Solheim, Boschma, & Herstad, 2020; Kaiser, Kongsted, Laursen, & Ejsing, 2018). It has been well documented that especially strong effects on firm innovation and technological repositioning are to be expected when firms hire workers who are technologically distant from the firms' expertise (Tzabbar, 2009; Markus & Kongsted, 2013). Another aspect that can differentiate workers is their country of origin and the country in which they acquired their education and formal training (Choudhury & Kim, 2019). Despite an increasing interest in the effects of immigration on innovation in aggregate, less remains known about the effects of hiring foreign workers on firm innovation.

This chapter differentiates between two types of innovation – exploration and exploitation. These two types differ in regard to their antecedents. Exploitation is commonly associated with a firm's ability to exploit existing knowledge and innovate incrementally along the firm's existing trajectory (March, 1991). Exploration requires a firm to look beyond its local boundaries and make use of knowledge in unfamiliar domains (March, 1991; Silverman, 1999; Kehoe & Tzabbar, 2015). By focusing on the transfer of knowledge across firm boundaries, the learning-by-hiring literature has emphasized the beneficial effects related to the recruitment, and actual mobility of, the new employees and the firm's innovative performance (Kaiser, Kongsted, & Rønde, 2015).

To address this research question empirically, this paper makes use of the Danish linked employer–employee data, which are merged with firm-level patent data from the European Patent Office (EPO). These data identify the annual movement of employees, their immigration background, their highest degree of education and job function, as well as the inventive output of the corresponding firm and the technology domains in which this activity is situated. Our analysis focuses on a set of 376 Danish R&D active firms between 2001 and 2013. It further exploits changes in the Danish preferential tax scheme for foreign researchers and key employees, as a (quasi) natural experiment to strengthen causal inference.

This chapter shows how the recruitment of foreign R&D workers not only positively affects the propensity of a firm to explore new technological fields, but also enhances the number of newly explored technological fields and the value of such innovations. Further, investigating the citation patterns of the patents filed by the hiring firm provides additional evidence, suggesting that firms hiring foreign R&D workers draw on more diverse solution sets and previously unexploited knowledge in the development of new technologies.

1.1.2 Chapter 3: Beyond scientific excellence: Are internationally mobile researchers more likely to become academic entrepreneurs?

In line with the previous chapter, Chapter 3 is concerned with the consequences of international mobility of highly skilled individuals. The extant literature investigates the relationship between the international mobility of scientists and their subsequent academic output (Scellato et al., 2012; S. P. Kerr & Kerr, 2016; Breschi & Lissoni, 2009; Hunt, 2010); however, the effects on knowledge transfer require further exploration.

Knowledge transfer and academic entrepreneurship rely on localized social networks and require specific knowledge about the local context (Stuart & Sorenson, 2007; Owen-Smith & Powell, 2003; Stuart & Ding, 2006), which may get disrupted during an entrepreneurial spell. International mobility has been linked to attributes and the acquisition of traits that are also associated with entrepreneurial entry (Borjas, 1987; S. P. Kerr & Kerr, 2016). Immigrants have been shown to be over represented among entrepreneurs, especially in knowledge-intensive ventures (Saxenian, 2000; Stephan & Levin, 2001).

Chapter 2 of this dissertation, therefore focuses on the relationship between the international mobility of scientists and academic entrepreneurship. Comparing the entrepreneurial activities of internationally mobile natives with their non-mobile native colleagues, this chapter finds a positive and significant difference between these groups in terms of the likelihood of starting a company, highlighting the possible benefits of international experience. However, when comparing the two groups of internationally mobile scientists -– returnees and immigrants -– I find that immigrants are significantly less likely to start a company in Denmark.

This chapter makes use of a representative survey, which contains detailed information on the mobility history and the entrepreneurial activity of 3,400 Danish academics and, is complemented with publication data from Scopus. Academic entrepreneurship is defined based on a survey question, which asked for the involvement of scientists in setting up a company based on their research. To estimate differences in probabilities of starting a company in Denmark, a discrete time hazard model is estimated. Another finding of this chapter pertains to the consideration of different types of international mobility. Thus, it does not solely consider immigrants but also internationally mobile native workers, i.e. returnees.

1.1.3 Chapter 4: The effects of academic entrepreneurship on knowledge production and collaboration in academia

This dissertation finishes by investigating the consequences of academic entrepreneurship in Chapter 4. Although a large strand of literature investigates the antecedents of academic entrepreneurship (Perkmann et al., 2013), surprisingly little remains known about how an entrepreneurial spell affects scientific knowledge production. The studies that have investigated the effects of academic entrepreneurship on productivity have mainly focus on one-time transitions (e.g., Toole & Czarnitzki, 2010). However, just like entrepreneurial spells outside academia (e.g., Manso, 2016), many spells of academic entrepreneurship are fleeting and the skills and experiences acquired through such spells are also likely to have long-term effects on various aspects of scientific knowledge production.

One such aspect is collaborative knowledge production. Over the past decades, collaboration and teamwork have become the dominant mode of knowledge production in science (Jones, Wuchty, & Uzzi, 2008; Rahmandad & Vakili, 2019; Jones, 2009). Therefore, it is important to investigate how the effects of entrepreneurial commercialization of scientific discoveries affect scientists' subsequent output as entrepreneurial spells and collaboration with industry have shown to affect research endeavors.

Thus, this chapter begs the question of how academic entrepreneurship affects the productivity and collaboration patterns of academic scientists, both during and after entrepreneurial spells. I answer this question using the Danish linked employer–employee data, which I matched with publication data from Scopus, covering the years 1999–2016. I focus on academics who start a company between 2004 and 2008, and conducted a case-cohort sampling design, matching the two closest non-entrepreneurial scientists, based on several observable demographic characteristics.

I find that academic entrepreneurship has negative effects on the productivity of scientists even after returning full time to academia, but that these effects do attenuate over time. I confirm prior findings by showing that academics shift their focus towards more exploratory research. Further, my results suggest a significant effect on collaboration, by inducing the exploration of new co-authors in the short run, but through fewer repeated co-author ties in the long run.

1.2 Contributions

This thesis advances the understanding of how individual-level characteristics and experiences shape the activities of academics and knowledge search in firm-level innovation. More specifically, Chapter 2 analyzes how hiring foreign R&D workers in contrast to native R&D workers, affects exploration. Chapter 3 investigates the consequences of international mobility in the context of academia. More specifically, it investigates the how different types of international mobility affect the propensity of entrepreneurial commercialization of their research. Chapter 4, the final chapter of this thesis, combines the ideas of the two prior chapters and investigates the consequences of entrepreneurial spells of academics on their research productivity and collaboration patterns. Below, I clarify in more detail how the individual papers contribute to different strands of literature.

Chapter 2, contributes to two streams of literature. The first stream of literature on immigration and innovation mainly focused on the mobility of individuals and implications for aggregate innovation (W. R. Kerr, 2010); less attention is paid to how foreign R&D workers contribute to the type of innovation at the organizational level (Laursen, Leten, Nguyen, & Vancauteren, 2019). This chapter finds that in contrast to native R&D workers, foreign hires have a particularly strong impact on exploration. A further contribution is made to the literature on learning by hiring (e.g., Song, Almeida, & Wu, 2003; Tzabbar, 2009), by emphasizing that not just cognitive distance between new and incumbent workers, but also the context in which professional experiences have been acquired can have an impact on search and innovation.

Chapter 3 of this thesis contributes to the literature on international mobility in science (Scellato et al., 2012) and academic entrepreneurship (Perkmann et al., 2013). Both phenomena have extensively been studied, but as international mobility becomes an increasingly common part of academics' careers, it is also important to investigate how international mobility effects scientists' careers, beyond their research productivity. My findings suggest that international mobility has a positive effect on entrepreneurship for native academics, which implies that traits and experiences associated with international mobility may indeed foster the entrepreneurial commercialization of scientific discoveries. However, immigrant academics are less likely to commercialize their discoveries through entrepreneurship, even after controlling for the motivations and taste for entrepreneurship. This highlights the importance of localized factors, such as networks, knowledge of the context, and recognition of opportunities for academic entrepreneurship. In sum, this chapter also adds to the literature that international mobility might also disrupt traditional channels of knowledge transfer; thus, it has also very practical and policy implications.

Finally Chapter 4 contributes to the literature on academic entrepreneurship (Toole &

Czarnitzki, 2010; Fini et al., 2021) and the literature on the economics of science (Myers, 2020; Teodoridis, 2018). Extending prior literature, this chapter conceptualizes academic entrepreneurship as both, a state and a treatment. It therefore investigates the persistence of the effects of academic entrepreneurship on productivity and collaboration patterns of scientists. The findings suggest that academic entrepreneurs face a 25% drop in productivity during their entrepreneurial spell, which closely resembles prior findings. It further shows that this discount also persists for up to five years after the spell has— ended. By further investigating changing collaboration patterns of former entrepreneurs, the findings suggest that even several years after the end of an entrepreneurial spell, former entrepreneurs explore more and repeat less co-authorships, even after controlling for shifting scientific fields. This might suggest that skills acquired through academic entrepreneurship are not fully transferable to collaborative knowledge production in science, and thus, might also be harmful to scientists' careers. These findings provide a starting point for future research.

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In search of new knowledge: When does hiring foreign R&D workers foster exploration?

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2.1 Introduction

It is well established that, in order to stay competitive over time, firms cannot solely rely on the exploitation of their existing knowledge and technologies, but need to explore novel technology fields simultaneously (March, 1991; Nelson & Winter, 1982). However, the increasing complexity of developing novel technologies and specialization of human capital has put pressure on firms to obtain access to external knowledge, while creating opportunities for learning and avoiding the duplication of ideas (e.g., Nelson & Winter, 1982; Henderson & Clark, 1990; March, 1991; Arora, Belenzon, & Patacconi, 2018; B. N. Bloom, Jones, Reenen, & Webb, 2020).

Extensive research has focused on the formal and informal mechanisms through which firms can overcome their local search constraints and identify, access, and integrate valuable knowledge that resides outside the boundaries of the firm for this purpose (e.g., Cohen & Levinthal, 1990; Rosenkopf & Nerkar, 2001; Rosenkopf & Almeida, 2003). As a result of the tacit and person-embodied dimension of scientific and technological knowledge, prior work has argued that the recruitment and mobility of R&D workers is an effective channel for firms to acquire access to external knowledge and skills (e.g., Song, Almeida, & Wu, 2003; Agarwal, Ganco, & Ziedonis, 2009). Yet, the degree to which firms are able to overcome local boundaries and explore novel technology fields through this channel depends on the relative novelty of the knowledge and skills these R&D workers bring (Markus & Kongsted, 2013). Whereas prior work has examined the contribution of scientists and R&D workers with experience in different industries (Tzabbar, 2009), little is known about the implications of the recruitment of R&D workers who acquired their knowledge and skills in different geographical contexts.

Notwithstanding the fact that a growing body of literature assesses the effects of skilled migration on innovation (Kerr & Lincoln, 2010; Hunt & Gauthier-loiselle, n.d.; Ghosh et al., 2015; Laursen et al., 2019), it remains unclear how the recruitment of foreign R&D workers – as opposed to the recruitment of native R&D workers – affects the exploratory character of firms' technology development activity. While a notable exception is provided by Choudhury and Kim (2019), who show that immigrants contribute to innovation through the reuse and recombination of knowledge locked in their home countries, an important question remains unanswered, namely, how do different geographical and technical backgrounds of foreign R&D recruits affect the exploratory character of hiring firms' inventive output..

This paper intends to fill this gap, by asking how hiring foreign R&D workers affects firm-level exploration. Specifically, we analyze when the recruitment of native and foreign R&D workers fosters firm-level exploration most significantly, by exploiting the heterogeneity of their educational qualifications and geographical origins to account for their relative distance vis-à-vis the hiring firm's incumbent R&D workforce. Building on previous research, we hypothesize that the recruitment of foreign R&D workers positively affects the exploratory character of the hiring firms' inventive output, and that this effect is stronger as compared to the effect of the recruitment of native R&D workers. We argue that hiring R&D workers, stemming from different geographical origins may not only provide access to knowledge that is not accessible within the recruiting firms' geographical boundaries (Jaffe, Trajtenberg, & Henderson, 1993; Moser, Voena, & Waldinger, 2018; Akcigit, Grigsby, & Nicholas, 2017; Hornung, 2014; Choudhury & Kim, 2019), but also that knowledge brought by R&D recruits originating from different geographical areas is likely to differ with respect to the setting in which it was acquired. As a consequence of country-specific attributes and differences in the institutional set-up, organizational practices, demand conditions, and cultural background across countries, even the skills and problem-solving perspectives brought by R&D workers stemming from different geographical contexts but with similar formal qualifications and active in the same technological areas as local R&D workers, may significantly differ (Bartholomew, 1997; Phene, Fladmoe-Lindquist, & Marsh, 2006; Scalera, Perri, & Hannigan, 2018; Ozgen, Peters, Niebuhr, Nijkamp, & Poot, 2014; Alesina, Harnoss, & Rapoport, 2016; Mattoo, Neagu, & Özden, 2012).

In order to address this research question empirically, we make use of the Danish linked employer-employee data and firm-level patent data from the European Patent Office (EPO).

This data allows us to accurately identify the annual movement of employees, their immigration background, their highest degree of education and job function, as well as the inventive output of the corresponding firm and the technology domains in which this activity is situated. Our analysis focuses on a precisely defined set of 376 Danish R&D active firms over the period from 2001 to 2013. In addition, we exploit an exogenous shock in the supply of high-skilled foreign workers introduced by an extension of the Danish preferential tax scheme for foreign researchers and key employees in 2008, as a (quasi) natural experiment to strengthen causal inference (Jacobsen Kleven, Landais, Saez, & Schultz, 2014; Akcigit, Baslandze, & Stantcheva, 2016).

The outcomes of our study provide robust evidence that the recruitment of foreign R&D workers positively affects the recruiting firms' subsequent exploratory activity, measured as the extent to which these firms develop technologies situated in previously unexplored technology fields. This effect is significantly larger than the corresponding effect related to the recruitment of native R&D workers. Yet, we find that this is only the case when these foreign R&D workers are hired from geographical contexts that are represented within firms' incumbent R&D workforce to a lesser extent. Further investigating the citation patterns of the patents filed by firms in our sample, we confirm that firms hiring foreign R&D workers draw on more diverse solution sets and previously unexploited knowledge in the development of new technologies. Interestingly, we show that, in contrast to native R&D hires, the recruitment of foreign R&D workers leads to increased levels of exploratory activity even when the similarity between the educational background of these new hires and firms' incumbent R&D workforce is high. This finding provides support for our expectation that, even though newly hired foreign workers are close to the firm's incumbent R&D workforce in terms of their educational backgrounds, their skills and knowledge might still serve as a source of exploratory insights as they bring different innovation-related problem-solving perspectives shaped by their distinct geographical background. Nonetheless, additional analyses show that the recruitment of such foreign R&D workers only moderately affects firms' technological repositioning. Solely foreign R&D hires for whom the educational distance between themselves and the firm's incumbent R&D workforce is large are positively and significantly related to a strong technological repositioning.

In summary, the contribution of this paper is twofold. First, our findings add to the existing literature on firm-level exploration by highlighting that the relationship between firm-level exploration and high-skilled R&D recruitment does not only depend on the technological content of newly hired R&D workers' knowledge, but also on the geographical context in which they acquired this knowledge. Second, this study contributes to the broad literature on immigration and innovation by showing how native and foreign R&D hires differently affect firm-level exploration, and by emphasizing the argument that foreign R&D hires are not merely substitutes for domestic R&D hires.

2.2 Theory & Hypotheses Development

We aim to investigate how newly hired foreign R&D workers – as opposed to newly hired native R&D workers – affect firm-level exploration. Whereas *exploitation* is commonly associated with local search leading to the development of incremental improvements along a firm's existing technology trajectory, the *exploration* of novel technology fields requires a firm to look beyond its local boundaries and to delve into unfamiliar technological component spaces (March, 1991; Silverman, 1999; Tzabbar & Kehoe, 2014). For the purpose of our study, we apply a firm-level perspective and define exploration as the successful development of technologies situated in previously unexplored technological fields from the perspective of the firm (Katila & Ahuja, 2002).

It is well established that a firm's ability to innovate depends to a large extent on the knowledge held by its employees (Felin, Foss, & Ployhart, 2015; Toh, 2014; Galunic & Rodan, 1998) and its capability to effectively organize and recombine this knowledge (Aggarwal, Hsu, & Wu, 2019; Dahlander, O'Mahony, & Gann, 2016; Paruchuri & Awate, 2017; Grant, 1996). However, the skills and routines required for exploitation and exploration are argued to be different. Exploitation is commonly associated with a firm's ability to exploit existing knowledge and innovate incrementally along the firm's existing trajectory (March, 1991).

Exploration, in contrast, requires a firm to look beyond its local boundaries and make use of knowledge in unfamiliar domains (March, 1991; Silverman, 1999; Tzabbar & Kehoe, 2014). Focusing on the transfer of knowledge across firm boundaries, the learning-by-hiring literature has emphasized the beneficial effects related to the recruitment, and actual mobility, of new employees and firms' innovative performance (e.g., Marx, Strumsky, & Fleming, 2009; Song et al., 2003; Agarwal et al., 2009; Singh & Agrawal, 2011; Cassiman, Veugelers, & Arts, 2018).

Consequently, the recruitment of workers bearing knowledge that is novel, relative to the knowledge held by a firms' incumbent workforce, is expected to have a particularly strong effect on exploration (e.g., Phelps, 2010). Accordingly, we argue that newly hired foreign R&D workers may present a source of novel and unfamiliar knowledge from the perspective of the recruiting firm, and positively affect this firm's exploratory technology development.

The existing literature points to various reasons as to why firms' newly hired foreign R&D workers may present a source of novel knowledge, and why this knowledge might be even more novel from the perspective of the recruiting firm than the knowledge brought in by newly hired native R&D workers. To start, foreign R&D workers are likely to have been exposed to a different set of technologies and organizational practices than have domestic R&D workers (Fleming, 2001; Gruber, Harhoff, & Hoisl, 2013). As a result of heterogeneity in the distribution of technological advantages, along with the localization of knowledge and its spatial concentration, different countries and regions possess distinct technological knowledge, and organizational practices differ largely across distinct geographical contexts (Jaffe et al., 1993; N. Bloom & Van Reenen, 2007; Delgado, Ketels, Porter, & Stern, 2012).

Moreover, differences in institutional set-up and demand conditions lead industries to evolve differently across different countries (Bartholomew, 1997; Phene et al., 2006; Scalera et al., 2018). Even the skills and problem-solving perspectives of R&D workers, stemming from different geographical contexts but with similar formal qualifications and active in the same technological area as local R&D workers, may still significantly differ as a result of their distinct cultural backgrounds and country-specific attributes (Ozgen et al., 2014; Alesina et al., 2016; Mattoo et al., 2012). The work of Phene et al. (2006) underlines the importance of considering knowledge's geographical origins in addition to its technological space, as they find that knowledge distant on either dimension enables a firm to make novel associations. In a related study, Tzabbar and Vestal (2015) show that geographically dispersed teams gain access to diverse knowledge and are therefore more likely to develop novel innovations. In contrast, if all workers share the same knowledge and backgrounds, which might be reinforced by co-location, novel ideas are unlikely to emerge (Amabile, 1988).

Additionally, foreign workers are likely to differ from natives in terms of their (professional) networks, and the type and scope of knowledge to which they have access (Solheim & Fitjar, 2018). Notably, knowledge has been shown to flow disproportionately through ethnic ties (Kerr, 2008; Breschi & Lissoni, 2009). Oettl and Agrawal (2008) have provided evidence that hiring foreign workers relates to an increased flow of knowledge from the workers' countries of origin to the recruiting firms. In addition, native and foreign R&D workers are expected to differ with respect to their individual problem-solving capabilities (Page, 2007; Berliant & Fujita, 2012). The study of Godart, Maddux, Shipilov, and Galinsky (2015) reveals that foreign professional experience and working in different contexts is linked to larger levels of creativity. Workers with such experiences have been shown to not only expose other workers to more novel ideas, but also to provide them with better abilities by which to communicate and implement such ideas (Godart et al., 2015; Galunic & Rodan, 1998).

Nonetheless, the recruitment of foreign workers may also cause communication and integration frictions. As reported by the diversity literature, returns to geographical or ethnic diversity decrease with an increased cost of communication. These costs can mainly be attributed to differences in language (Bathelt, Cantwell, & Mudambi, 2018). However, the existence of a language barrier is likely to diminish with the degree of education and proficiency in a common language, e.g., English. Highly skilled R&D workers can be expected to be proficient in English, particularly with respect to their domain of technological expertise, as most scientific and professional literature is published in English. The integration costs firms face when hiring highly skilled migrants are discussed in depth by Laursen et al. (2019). Similarly, they argue that the cost of integration and acculturation is inversely related to the level of education. Thus, when considering foreign R&D workers, communication and integration costs can be expected to be limited and are unlikely to hamper the transfer and integration of knowledge.

By combining the abovementioned streams of literature and further building on recent insights from the literature on immigration and innovation (Hornung, 2014; Moser et al., 2018; Laursen et al., 2019; Choudhury & Kim, 2019), we argue that foreign R&D workers who newly enter a firm are more likely to provide the firm with novel insights and different innovation-related problem perspectives as compared to native R&D recruits, for two main reasons. First, foreign R&D workers are more likely to be educated in different fields and, therefore, are specialized in different technologies. Second, the knowledge and problem-solving perspectives brought by foreign R&D workers most likely differ with regard to the context in which they were acquired and are, therefore, shaped by distinct cultural backgrounds, knowledge networks, organizational practices, institutional set-up, demand conditions and country-specific attributes. In sum, we predict that, by hiring foreign R&D workers, firms may increase the potential of novel ideas stemming from their R&D workforce, and gain access to new and complementary pieces of knowledge. Moreover, we argue that foreign R&D workers who newly enter a firm are more likely to provide the firm with novel insights and different innovation-related problem perspectives as compared to native R&D recruits. As accessing such knowledge is key for organizations to explore novel technology fields, our baseline hypotheses are the following:

Hypothesis (H1a): *Newly hired foreign R&D workers are positively related to the hiring firm's exploratory technology development.*

Hypothesis (H1b): *Newly hired foreign R&D workers are more positively related to the hiring firm's exploratory technology development than are newly hired native R&D workers.*

Despite the expectation that hiring foreign R&D workers is positively related to a firm's exploratory technology development, the effects are likely to differ, depending on the relative novelty of the knowledge and skills these R&D workers actually bring. Based on the findings of prior work (e.g., Laursen et al., 2019) and the arguments made in the previous section, we expect that hiring R&D workers from geographical contexts, that are to a lesser extent presented within a firm's incumbent R&D workforce, will provide the firm access to relatively more novel knowledge and skills, and consequently will foster subsequent firm-level exploration in a more intensive manner. We argue that by increasing the scope of origins of its R&D hires, firms increase the set of new ideas entering the firm and opportunities for recombination.

Nevertheless, while the generation of ideas is commonly positively associated with knowledge dissimilarity (e.g., Cohen & Levinthal, 1990; Parrotta, Pozzoli, & Pytlikova, 2014; Hoisl, Gruber, & Conti, 2017), previous literature has also established that learning potential decreases if knowledge stocks are too diverse (Hamel, 1991; Mowery, Oxley, & Silverman, 1996; Sampson, 2007; Nooteboom, 2000; Fleming & Sorenson, 2004). Theories surrounding organizational learning emphasize that a balance needs to be established between the opportunity of accessing novel insights on the one hand, and the risk of increased communication, coordination, and integration costs on the other hand (Mowery, Oxley, & Silverman, 1998; Sampson, 2007; Nooteboom, 2000). Thus, such integration frictions might be particularly present when firms aspire to access and integrate the knowledge originating from previously unexplored geographical contexts. These costs relate primarily to the de-contextualization of knowledge and adaptation to the internal context of the firm (Bathelt et al., 2018; Hansen, 1999). Yet, in view of our study, these frictions are expected to be substantially reduced as a result of the actual mobility of the workers in which the relevant knowledge is embedded. Establishing relational strength at the individual level through frequent interactions has been argued to facilitate the transfer of knowledge, and to lower the communication and integration costs (Tzabbar & Vestal, 2015). Moreover, when highly educated and skilled R&D workers are hired, relational strength is likely to build up fast, as these workers are co-located, share a scientific background, work together on a regular basis, and communication costs are expected to be limited (Gittelman, 2007; Berry, 1997; Laursen et al., 2019). For these reasons, we expect the exploration-related benefits of hiring high-skilled R&D workers from novel geographical origins to outweigh a potential increase in communication and integration costs.

In light of the literature discussed, we argue that continuously hiring foreign R&D workers from the same geographic location is more likely to result in redundancies of knowledge and skills, which will affect firms' exploratory technology development less intensively. In short, we expect that hiring R&D workers from geographical contexts that are to a lesser extent represented within a firm's incumbent R&D workforce will bring about beneficial learning opportunities and fuel firm-level exploration most significantly. Thus, we posit the following hypothesis:

> **Hypothesis (H2):** *The positive relationship between hiring foreign R&D workers and firm-level exploration is most pronounced when the overlap in geographical origins between these R&D workers and the hiring firms' incumbent R&D workforce is low.*

As discussed, prior literature has pointed out that the recruitment of individuals with different educational and technological backgrounds enables firms to access novel knowledge (e.g., Almeida & Kogut, 1999) and is positively associated with exploration (e.g., Tzabbar, 2009). The importance of simultaneously considering knowledge's geographical origins and technological dimensions, has been emphasized by the work of Phene et al. (2006). Investigating the interaction of technological distance and geographical origins of external knowledge accessed in the production of breakthrough innovations, they find that knowledge distant on either dimension enables a firm to make novel associations. Extending these arguments, this paper proposes that foreign R&D hires – as opposed to native R&D hires – may not only foster the hiring firm's exploratory technology development by providing access to technologically distant knowledge, but that also their unique innovation-related problem-solving perspectives shaped by their distinct geographical origins may increase the relative novelty of the knowledge and skills these R&D workers bring, and serve as a source of exploratory insights. To find support for this claim, it is highly relevant to evaluate the contributions of R&D hires while accounting for the educational distance between these hires and firms' incumbent R&D workforce.

Specifically, we hypothesize that newly hired foreign R&D workers will positively relate to firms' exploratory technology development even at high levels of educational similarity with the recruiting firms' incumbent R&D workforce. We argue that, despite being close to firms' incumbent workforce in terms of their educational background, the skills and knowledge of foreign R&D workers might still significantly differ from those of native R&D workers because of their distinct geographical context and cultural background (Ozgen et al., 2014; Alesina et al., 2016; Mattoo et al., 2012). Due to different applications of technologies and country-specific attributes, foreign R&D hires, even when active in the same technological area, are not merely perfect substitutes for their native counterparts and are, therefore, expected to provide novel knowledge and insights that might foster exploration.

In contrast, we expect that hiring native R&D workers with very similar educational backgrounds as that of firms' incumbent R&D workforce will lead to an increased duplication of ideas and will inhibit the exploration of technological opportunities situated outside firms' established fields of expertise. Given that the knowledge embedded in R&D recruits who received their education and gained work experience within the firm's national boundaries has been shaped by a similar scientific, technological, institutional and cultural environment, as well as by the same country-specific attributes, we propose that the extent to which hiring such R&D workers presents a source of novel ideas and distinct innovation-related problem-solving will highly depend on the overlap in the educational background between these hires and the recruiting firms' incumbent R&D workforce. In summary, we hypothesize as follows:

> **Hypothesis (H3):** *In contrast to native R&D hires, foreign R&D hires are positively related to firm-level exploration even if the educational similarity between themselves and firms' incumbent R&D workforce is high.*

2.3 Data, Variables, & Methodology

2.3.1 Sample Construction

In order to address the proposed research questions, we construct a panel dataset of all Danish innovation-active firms over the period from 2001 to 2013.[1] We include all private Danish firms with at least one EPO patent application over this period, employing a minimum of five employees of which at least one is an R&D worker (on a yearly basis). Patent data is sourced from the PATSTAT database (spring edition 2018) and employer-employee data is taken from the Danish registry data, provided by Denmark Statistics.[2] In correspondence with Kaiser et al. (2015) and Kaiser et al. (2018), we define R&D workers as those employees within a firm who are likely to be engaged in R&D-related tasks. In order for an employee to be identified as an R&D worker, two main criteria must be satisfied. First, (i) this employee needs to hold a master's or doctoral degree in technical or natural science, veterinary and agricultural sciences, or health sciences (Kaiser et al., 2018). Further, since not all high-skilled workers are necessarily conducting R&D related tasks, (ii) the second criterion requires the identified high-skilled workers' job functions to involve the use or production of knowledge at an advanced level. For this purpose, we rely on the International Standard Classification of Occupations (ISCO) included in the Danish registry data. In addition, to be classified as an R&D worker, these individuals must be aged between 20 and 75 years. Our final sample includes 3,732 firm-year observations of 376 unique R&D active firms over the period 2001–2013.

As a robustness check, a second, more restricted, sample is constructed by utilizing coarsened exact matching (CEM) in order to decrease the likelihood that potential pre-treatment differences between treated and control firms confound our results (see section 2.4.4).

[1]We focus on the 2001–2013 time period as this is the longest period for which consistent firm identifiers are available in our dataset.

[2]EPO data does not have a unique firm identification number of the type used by Statistics Denmark; therefore, the EPO data was mostly manually attached to Statistics Denmark's firm identifiers (Kaiser, Kongsted, & Rønde, 2015)

2.3.2 Variables

Dependent variables

Conceptually, we apply a firm-level lens and define *exploratory activity* as technology development situated in technology fields that are novel from the perspective of the firm (Katila & Ahuja, 2002). In order to identify the novel character of firms' technology development, firms' technological activities in new or existing technology fields are measured by means of the technology class information assigned to their patents (Belderbos, Faems, Leten, & Van Looy, 2010). For this purpose, the IPC (international patent classification) 4-digit level is used. We consider a technology class as *exploratory* if the firm has previously not patented in that technology field. The variable *Exploratory Patent Count* accounts for the number of technologically novel patents filed by firm i in year t, that is, patents situated in a technology field in which the firm has not patented before.[3,4,5,6]

Notwithstanding our focus on firms' exploratory activity, we aim to place our findings into broader perspective by simultaneously examining how the recruitment of native and foreign R&D workers relates to hiring firms' subsequent *non*-exploratory technology development activity. This also allows us to better understand to what extent our findings may be driven by an increase in firms' overall innovative productivity. To this end, the variable *Non-Exploratory Patent Count* is constructed and accounts for the number of patents filed in non-novel technology classes from the perspective of the firm – that is, technology classes in which the firm has already previously patented.

[3]In case more than one technology class is assigned to a patent, that patent is considered as *exploratory* if at least one of the assigned technology classes is new to the firm.

[4]As a robustness check, we apply a five-year window: we consider a technology class as novel-to-the-firm in application year t, if the firm has not patented in the relevant technology domain over the past five years (*t-5* to *t-1*). All results are robust.

[5]As a robustness check, we use the count of exploratory technology fields in which firm i has been active in year t as opposed to the count of exploratory patents filed by firm i in year t. All results are robust to using this dependent variable.

[6]As a robustness check, we attempt to control for potential differences in the quality and value of the exploratory patents and weigh each exploratory patent by the number of subsequent patent citations it receives. All results are robust.

Independent variables

Native and foreign R&D hires: We divide the group of R&D workers employed at the firms included in our sample into two groups: *native* R&D workers and *foreign* R&D workers. In order to differentiate between both types, we rely on the immigration data present in the registry data provided by Denmark Statistics.[7] Next, we identify the mobility status of the different groups of high-skilled workers: high-skilled workers are considered new hires or joiners in their first year active at the firm. Accordingly, the variables *Share New Native R&D Hires* and *Share New Foreign R&D Hires* take into account the ratio of native and foreign R&D workers joining firm i in year t to all R&D workers employed at firm i in year t.[8]

Similarity in geographical origins: The similarity in geographical origins between the recruited foreign R&D hire(s) and firms' incumbent R&D workforce is taken into account to evaluate how this similarity affects the effect of new foreign R&D hires on the exploratory character of firms' inventive output. By calculating the similarity in geographical origins of foreign R&D hires and firms' incumbent R&D workers – based on their last country of residence – we aim to take into account the amount of potential each cohort of hired foreigners holds as a source of non-redundant knowledge and skills. We measure the (dis)similarity in geographical origins between newly hired foreign R&D workers (vector $F_{NH_{for}}$) and firms' incumbent R&D workers (vector F_{INC}) as an angular distance. Thus, the vector $F_{NH_{for}} = (F^1, F^2, ..., F^S)$ represents the shares of newly hired foreign R&D workers originating from country S. Hence, the (dis)similarity in terms of geographical origins between these newly hired foreign R&D workers and firms' incumbent R&D workers is calculated in the following manner:

$$Angular\ distance\ in\ geo.\ origins = cos^{-1}\frac{F'_{NH_{for}}F_{INC}}{\sqrt{(F'_{NH_{for}}F_{NH_{for}})(F'_{INC}F_{INC})}}$$

[7]Note that we do not consider R&D workers who migrated to Denmark before the age of 21 as highly skilled *foreign* R&D workers in order to guarantee that high-skilled foreign R&D workers obtained (at least part of) their higher education abroad.

[8]For example, if a firm employs a total of 100 R&D workers in year t and 5 of them are foreigners hired in year t, the share of new foreign R&D hires is 0.05.

The resulting angular measure goes from 0 to $\frac{\pi}{2}$: 0 indicates that there is a complete overlap in geographical origins between both groups, while the maximum value indicates that there is no overlap in the geographical origins of both groups. In our econometric analysis, we consider the geographical similarity between recruited foreign R&D hires and the incumbent R&D workers to be *low* when this overlap is larger than the median of the overlap in geographical origins between foreign R&D recruits and incumbent R&D workers. Consequently, the geographical similarity between each (group of) foreign R&D worker(s) a firm hires in a given year, and that firm's incumbent R&D workforce, is either low or high.

Similarity in educational backgrounds: The educational similarity between the recruited native and foreign R&D hires on the one hand, and firms' incumbent R&D workforce on the other hand, is taken into account to evaluate how this similarity affects the effect of newly hired R&D workers on the exploratory character of firms' inventive output. Owing to the detailed Danish registry data, we were able to rely on the educational backgrounds of R&D workers to determine the cognitive distance between new hires and incumbents. Previous studies have identified education as a key factor that influences individuals' cognitive ability (Gruber et al., 2013; Markus & Kongsted, 2013; Holland, 1973; Pelled, 1996). The 8-digit educational classification provided by Statistics Denmark provides information on each R&D worker's highest completed degree and denotes the area and level of their tertiary education.[9] To identify the similarity between the educational background of newly hired R&D workers and a firm's incumbent R&D workforce, we measure the angular distance between both groups in a similar fashion as done for the similarity in geographical origins. The resulting angular measure goes from 0 to $\frac{\pi}{2}$: 0 indicates that there is a complete overlap in the educational backgrounds of both groups, while the maximum value indicates that there is no overlap in the educational background of both groups. We consider the educational

[9]The educational class system allows to differentiate between the level as well as content of a degree. To illustrate this with an example: Take education code 653580. The first two digits (65) indicate that the individual holds a master's degree. The following digits (35) define the middle group, that is natural sciences. The next two digits (80) then define the subgroup – that is, biology – which can further be divided into different sub-disciplines such as Molecular Biology (65358048) or Environmental Biology (65358036).

similarity between newly hired R&D workers and incumbent R&D workers to be *low* when the educational distance between both groups is larger than the median of the educational distance between foreign R&D recruits and incumbent R&D workers. Thus, the educational similarity between each (group of) foreign R&D worker(s) a firm hires in a given year, and that firm's incumbent R&D workforce, is either low or high. The same holds for native R&D hires.

Control variables

In order to obtain consistent estimates, the following variables are included in the presented econometric analyses to control for firm- and industry-specific factors that might affect firms' technological activity and exploratory endeavors. First, we control for the size of the firm by including the natural logarithm of the number of employees. Second, we control for the R&D intensity of the firm by dividing the number of incumbent R&D workers by the firm's total number of employees. Next, we take into account the patenting experience of the firm by controlling for its accumulated patent stock. Patent stock is measured as the natural logarithm of the total number of EPO patents applied for by the firm over the last five years, prior to year t. Fourth, we take into account the share of a firm's patents resulting from international collaborations, by dividing the number of patents co-applied with an international partner over the last five years by the total number of patents applied for by that firm over the last five years. Fifth, we account for the educational diversity among each firm's R&D workforce based on the variety in the educational background of the incumbent R&D workers. We utilize the inverse Herfindahl index for this purpose and determine how equally populated the different educational classes are with incumbent R&D workers (based on the 8-digit educational class system provided by the Danish registry data[10]). In a sim-

[10]The educational class system allows to differentiate between the level as well as content of a degree. To illustrate this with an example: Take education code 653580. The first two digits (65) indicate that the individual holds a master's degree. The following digits (35) define the middle group, that is natural sciences. The next two digits (80) then define the subgroup – that is, biology – which can further be divided into different sub-disciplines such as Molecular Biology (65358048) or Environmental Biology (65358036).

ilar fashion, we account for the geographical diversity among each firm's incumbent R&D workforce. Finally, industry and year fixed-effects are included in all models to control for industry- and year-specific effects.

Unobserved heterogeneity and state dependence. Since certain firms may be more likely to explore novel technology domains than others, for unobserved reasons, it is important to account for unobserved firm heterogeneity and state dependence in our econometric analysis. Following the logic of Blundell's pre-sample mean estimator approach (Blundell, Griffith, & Reenen, 1995; Blundell, Griffith, & Van Reenen, 1999), we aim to proxy for this unobserved firm-level heterogeneity by including firm-specific historical averages of the relevant indicator. More specifically, we include the natural logarithm of the average of *exploratory* patents applied for by the firm over the last five years prior to year t.[11] Because 30% of our observations relate to firms that have not filed any *exploratory* patent over the last five years, we follow Kaiser et al. (2018) and substitute an arbitrary small constant to allow for the logarithmic transformation and account for this substitution through the inclusion of a dummy variable, which is 1 if the firm has filed at least one exploratory patent over the last five years. To control for possible state dependence in the exploratory character of a firm's inventive output, we follow the approach of Crépon and Duguet (1997) and include a dummy variable that indicates whether or not a firm has filed an *exploratory* patent in the previous period (Kaiser et al., 2015). Note that, as a result of the inclusion of the variables that directly relate to firms' past exploratory patent activity, estimating a simple model including dummy variables for each firm would produce inconsistent estimates due to endogeneity issues (Blundell, Griffith, & Windmeijer, 2002).

2.3.3 Methodology

Taking into account that the main dependent variables are count variables with only non-negative integer values, non-linear count data models should be applied. Hence, we

[11] We do not solely rely on the pre-2001 patent information for this purpose as this would lead to a substantial loss of observations.

estimate negative binomial models, which are robust to the over-dispersion encountered in our data. Standard errors are clustered at the firm level. The main regression models presented in our paper are regressions of the following form:

$$y_{ijt} = \beta_1 HS\ Native\ Hires_{ijt-1} + \beta_2 HS\ Foreign\ Hires_{ijt-1} + \gamma_{ijt} + \lambda_t + \phi_j + \varepsilon_{ijt}, \quad (2.1)$$

where y_{ijt} denotes the outcome of firm i operating in industry j at time t. $HS\ Native\ Hires$ denotes the share of high-skilled native hires by a given firm i operating in industry j, at time $t-1$, and $HS\ Foreign\ Hires$ denotes the share of high-skilled foreign hires by that firm at time $t-1$. All labor variables are lagged with one year. γ presents the constructed firm-year level control variables. Finally, λ and ϕ are year and industry fixed-effects, respectively, and ε is the residual. Multicollinearity does not appear to be at play, since the average variance inflation factors (VIF) of the full models are all below 3 and the VIF of each variable in the model is below 5 (Baum, 2006).

In order to strengthen causal inference, we complement these models with a (quasi) natural experiment based on the exogenous shock in the supply of high-skilled foreign workers introduced by an extension of the duration of the Danish preferential tax scheme for foreign researchers and key employees in 2008. We elaborate on this in section 2.4.3.

2.4 Analyses & Results

This section presents the results of the different analyses conducted in our study. First, the descriptive statistics with respect to the constructed variables are discussed. Second, we examine how native and foreign R&D hires relate to the exploratory character of the inventive output of the hiring firm. Next, we use the exogenous shock in the supply of high-skilled foreign workers introduced by an extension of the duration of the Danish preferential tax scheme for foreign researchers and key employees in 2008, as a (quasi) natural experiment to strengthen causal inference. Finally, a wide range of additional analyses and robustness checks is presented with the purpose to better understand our findings and to rule out alternative explanations.

2.4.1 Descriptive statistics

Table 2.1 presents the summary statistics of the variables under study. The average ratio of newly hired high-skilled natives and newly hired high-skilled foreigners to all high-skilled employees for the 376 Danish R&D active firms in our sample is 0.192 and 0.012, respectively. In absolute numbers, firms hired approximately 5.8 high-skilled native R&D workers and 0.4 foreign R&D workers per year over the period 2001–2013. The average educational distance between high-skilled native R&D hires and firms' incumbent R&D workforce is 0.905, while this distance is equal to 1.061 for high-skilled foreign R&D hires. This confirms that foreign R&D hires differ, on average, more from firms' incumbent R&D workforce with respect to their educational background as compared to native R&D hires. Further, the average likelihood of sampled firms to undertake exploratory activity and patent in novel or previously unexplored technological fields is approximately 0.18 (*Exploratory activity*). Firms included in our sample file on average 0.34 exploratory patents and 2.01 non-exploratory patents per year.

— Insert tables 2.1 and 2.2 about here —

2.4.2 Econometric results

Estimation 1 in Table 2.3 tests our baseline hypotheses which posit that newly hired foreign R&D workers are positively related to the exploratory character of the subsequent inventive output of the hiring firm (H1a), and that this effect is significantly larger than the corresponding effect related to the recruitment of native R&D workers (H1b). The results of this estimation provide support for both hypotheses by showing that highly skilled foreign hires are indeed positively related to the number of patent applications situated in novel technology fields from the perspective of the firm, while no such effect is found for highly skilled native hires. A Wald test reveals that both coefficients are significantly different from each other (p-value ≤ 0.05). Estimating the corresponding elasticity, we find that a

1% increase in the ratio of newly hired foreign R&D workers is related to a 2.4% increase in the number of exploratory patents filed by the hiring firm.[12] Hence, this corresponds to an increase of approximately 26% in the development of exploratory technologies for a firm employing a total of 10 R&D workers of which one is a newly hired highly skilled foreigner.[13]

In order to place this finding into broader perspective, Estimation 2 tests how the recruitment of native and foreign R&D workers relates to the hiring firms' subsequent *non-*exploratory technology development activity. The outcomes of the negative binomial model on the count of patents filed in non-novel technology classes corroborate that the presented positive relationship between high-skilled foreign hires and the count of exploratory patents filed by the hiring firm is not simply driven by a productivity effect. We show that there is no significant relationship between the recruitment of high-skilled foreign R&D hires and the number of non-exploratory patents subsequently filed by the hiring firm, while a positive effect is found for high-skilled native hires in this context. Note, however, that the coefficients of both groups of new hires are not significantly different from each other.

— Insert table 2.3 about here —

Subsequently, Estimation 1 in Table 2.4 tests hypothesis 2 (H2) and examines how the similarity in geographical origins between the recruited foreign R&D hire(s) and a firm's incumbent R&D workforce affects the effect of hiring foreign R&D workers on the count of exploratory patents filed by the recruiting firms. We find that the recruitment of foreigners stemming from geographical origins that are to a lesser extent represented within a firm's incumbent R&D workforce (*Low geo. similarity*) is positively related to a firm's subsequent exploratory activity, while the coefficient for hiring foreigners from geographical origins that are to a greater extent represented within the firm's incumbent R&D workforce becomes insignificant (*High geo. similarity*). Wald tests point out that the coefficient corresponding to hiring foreigners stemming from geographical origins that are to a lesser extent represented within a firm's incumbent R&D workforce is indeed significantly different from recruiting

[12] $exp(2.303/100) - 1 = 0.024$

[13] Based on predictive margins.

native R&D workers. Yet, we do not find that the coefficients related to both groups of foreign hires, i.e. *Low geo. similarity* versus *High geo. similarity*, are significantly different from each other.

In correspondence to Table 2.3, Model 2 in Table 2.4 tests how the recruitment of these R&D workers relates to the hiring firms' subsequent *non*-exploratory technology development activity. Accordingly, we do not find a significant effect of the recruitment of foreigners stemming from geographical origins that are to a lesser extent represented within the firm's incumbent R&D workforce (*Low geo. similarity*), while the coefficient for hiring foreigners from geographical origins that are represented within the firm's incumbent R&D workforce to a greater extent now becomes (weakly) significant (*High geo. similarity*).

Model 3 in Table 2.4 tests hypothesis 3 (H3) by evaluating how the similarity in educational backgrounds between the recruited R&D worker(s) and firms' incumbent R&D workforce relates to the exploratory character of the hiring firm's subsequent inventive output, while explicitly distinguishing between native and foreign hires. While the results presented in Table 2.3 suggest that high-skilled native hires do not significantly relate to the exploratory patent count of the hiring firm, we now find a significant and positive relationship between the share of native R&D hires and the exploratory inventive output of the hiring firm, when the educational similarity between those hires and the firm's incumbent R&D workforce is low. With regard to the share of new foreign R&D hires, we find a strong and positive relationship between hiring foreign R&D workers and the exploratory inventive output of the hiring firm when the educational similarity between these recruits and the firm's incumbent R&D workforce is high. As the coefficients corresponding to native R&D hires and foreign R&D hires for whom the similarity in educational backgrounds between themselves and firms' incumbent R&D workforce is high, are significantly different from each other, the outcomes of this regression provide support for hypothesis 3. Note that, in case the similarity in educational background between the foreign recruits and the firm's incumbent R&D workforce is low, the relation between hiring such R&D workers and firms' exploratory technology development is only weakly significant ($p = 0.105$). This finding might suggest that, despite the actual mobility of foreign R&D workers from home to host country, firms still face certain barriers to absorbing the knowledge embedded in these foreign workers at high levels of educational dissimilarity.

Exploring the relation between the different groups of R&D recruits and the hiring firms' subsequent *non*-exploratory technology development activity in Model 4, we find that only the recruitment of native R&D workers, for whom the educational similarity between themselves and the firm's incumbent R&D workforce is high, is related to a significant increase in non-exploratory patent count.

— Insert table 2.4 about here —

2.4.3 Additional analyses

A natural experiment: the Danish preferential tax scheme

A main challenge in identifying the causal relationship between foreign R&D hires and firms' exploratory activity results from the fact that firms do not randomly select into hiring foreigners. In an attempt to deal with this challenge, we exploit a natural experiment related to changes in the duration of the Danish preferential tax scheme. This scheme, introduced in 1992, granted a 25% flat tax for foreign researchers and key employees for an initial period of three years. In the absence of this special tax scheme, these employees might face an average income tax rate of up to twice as high as the scheme rate (Jacobsen Kleven et al., 2014). In 2008, eligible employees were given the choice between a five-year scheme with a tax rate of 33% and a three-year scheme with a tax rate of 25%.[14] This extension, which was exogenous to most firms and immigrants, introduces an exogenous variation in the supply of foreign R&D workers, as it increases the incentives to migrate to Denmark as well as to those planning to stay for a longer period. While this extension may appear to be only a minor improvement, highly skilled workers' location choices have been found to be very sensitive to small variations in tax rates (Moretti & Wilson, 2017;

[14]For a detailed overview, see `https://www.skat.dk/skat.aspx?oid=107035&chk=200213`

Jacobsen Kleven et al., 2014; Akcigit et al., 2016). To exploit this source of exogenous variation, we build on the assumption that not all R&D active firms will be affected by the tax change to the same extent. More specifically, we make use of the fact that, already prior to the extension of the tax scheme, industries differed in terms of the extent to which they relied on the local knowledge supply, as revealed by the extent to which firms operating in these industries employed foreign R&D workers. Therefore, we argue that the extension of the duration of the preferential tax scheme will have larger effects on firms operating in industries that rely on foreign R&D workers to a larger extent. Thus, our goal is to investigate whether the exogenous change in the supply of foreign R&D workers affected firms' exploratory activity differently, in accordance with the dependency on foreign R&D workers in the industry in which they operate. Our identification comes from a difference-in-differences model, using firms located in *high-skilled immigration-dependent industries* as the treated group. The treatment period is the period subsequent to the tax change introduced in 2008. We analyze the timeframe from four years before the extension of the duration of the tax scheme until four years after. Only firms active in both periods are taken into account, thereby resulting in a subsample of 287 distinct R&D active firms over that period. An industry is considered to be a *high-skilled immigration dependent* industry if the average share of foreign R&D workers active in this industry is above the median of the average share of foreign R&D workers active in all industries included in our sample. Figure 2.1 confirms our expectations and indicates that the share of foreign R&D hires in a firm's R&D workforce increases significantly after the introduction of the tax change for firms situated in high-skilled immigration-dependent industries.

— Insert figure 2.1 about here —

We now employ our firm-year level data to estimate the following regression equation:

$$\begin{aligned} y_{ijt} &= \alpha + \beta_1 HS\,Immigr.\,Dep.\,Ind._{ij} + \beta_2 TaxShock_t \\ &+\gamma\, HS\,Immigr.\,Dep.\,Ind._{ij} \times TaxShock_t + \delta_{ijt} + \phi_j + \lambda_t + \varepsilon_{ijt}, \end{aligned} \tag{2.2}$$

where y_{ijt} represents the outcome of firm i operating in industry j in year t, and ϕ_j and λ_t

are industry and year fixed effects, respectively. δ_{ijt} denotes the constructed firm-year level control variables. The variables $HS\,Immigr.\,Dep.\,Ind._{ij}$ and $TaxShock_t$ are dummies for whether firm i is operating in an industry that is classified as being dependent to a larger extent on foreign R&D workers, and whether the firms' technology development activity took place within the treatment period beginning in 2008. The β coefficients capture the time-invariant difference in the development of new-to-the-firm technologies between firms situated in industries that depend to a larger extent on high-skilled immigration, and firms situated in industries that rely on high-skilled immigration to a lesser extent (β_1) and the change in their exploratory inventive output over time (β_2). The key coefficient of interest is the interaction term γ, which captures the increase in exploratory technology development caused by extending the duration of the preferential tax scheme for firms situated in high-skilled immigration-dependent industries.

Table 2.5 presents the results of the estimation of the difference-in-differences specification. In Model 1, we run a logit model on the dependent variable *Exploratory Activity*, a dummy variable that is 1 if a firm has explored novel technology fields in year *t*, and 0 otherwise. The coefficient from the interaction term (*Tax Change * Hs. Immigr. Dep. Ind.*) provides evidence that the tax change increases the likelihood that firms operating in industries that rely on foreign R&D workers to a relatively large extent undertake exploratory activity. The introduction of the tax change leads to an increase of 5.5 percentage points in the likelihood of these firms to undertake technology development activities situated in technology fields that are novel to them. In Model 2, we run a negative binomial model on the number of patents filed in novel technology classes in a given year from the perspective of the firm. The coefficient of the interaction term (*Tax Change * Hs. Immigr. Dep. Ind.*) suggests that the extension of the duration of the tax scheme has a positive and significant impact on the exploratory activity undertaken by firms operating in industries that rely on foreign R&D workers to a relatively large extent. We find that the tax change led to an increase of 49% in the number of patents filed in previously unexplored technology fields for firms situated in industries with a relatively higher dependence on foreign R&D workers.

— Insert table 2.5 and figure 2.2 about here —

Next, we continue by exploring the impact of the steep increase in the share of foreign R&D hires in a firms' R&D workforce directly after the tax change, for firms situated in industries highly dependent on foreign R&D workers, by means of running a dynamic difference-in-differences analysis. Thus, we include interactions between the *high-skilled immigration-dependent industry* dummy and the different year dummies in our negative binomial model. Figure 2.2 presents the outcomes of this analysis by plotting the coefficients corresponding to the created interaction dummies. The results provide clear evidence that the number of patents in previously unexplored technology fields for firms situated in high-skilled immigration-dependent industries increased significantly after the preferential tax scheme duration was extended. This effect is most pronounced (economically as well as statistically) for the year 2009, due to the very strong increase in the share of foreign R&D hires in immigration-dependent firms' R&D workforce in 2008 (see Figure 2.2), and, thus, confirms our earlier results. Moreover, Figure 2.2 reveals that none of the interaction coefficients are statistically significant during the pre-treatment period, thereby supporting the difference-in-differences assumption of parallel trends.

One may question the validity of the analysis by questioning the short-term impact of the extension of the tax scheme, as one may expect this to have a lasting effect. Given the onset of the financial crisis in 2009, and a general downturn of the local economy, a reduction in hiring foreign workers does not appear surprising. Additionally, this would only compromise the validity of our analysis if the short-term increase was driven by firms' internal efforts to increase the share of high-skilled foreign R&D workers.

Technological repositioning

In the analyses presented so far, we have investigated the relationship between newly hired R&D workers and firms' subsequent exploratory activity, as measured by firms' patenting activity in previously unexplored technology classes. However, note that the exploration of novel technology fields does not necessarily imply that a firm significantly changes its technological position. This brings up the question of the extent to which the outcomes of our "exploration" analyses hold when applying a more comprehensive outcome measure that takes into account all technological fields in which a firm patents in. In this additional analysis, we therefore build on the work of Tzabbar (2009) to construct an alternative dependent variable and test whether and when the recruitment of high-skilled foreign R&D workers may lead to significant technological repositioning. To this end, an outcome variable that indicates whether the technological activity undertaken by firm i in year t has changed that firm's technological position (i) rarely, (ii) moderately, or (iii) strongly as compared to year *t-1*, is constructed. More formally, we measure the technological distance between the patents filed by firm i in year t (vector $IPC_{Patents\_t}$) and its patent portfolio up to year *t-1* (vector $IPC_{PatPort\_t-1}$) as an angular distance (see section 3.2.2). For example, the vector $IPC_{Patents\_t} = (IPC^1, IPC^2, ..., IPC^S)$ represents the shares of patents filed in IPC class S by firm i in year t.[15] As most firms change their technological position regularly, technological repositioning is considered *strong* if this angular distance is greater than the average by more than one standard deviation. Technological repositioning is considered to be *moderate* if the angular distance between the technology classification of the patents filed by firm i in year t and the technology classification of that firm's complete patent portfolio up to year *t-1* is larger than the average by a standard deviation of over 0.5, but smaller than the average by a standard deviation of over 1. If the angular distance between the technology classification of the patents filed by firm i in year t and the technology classification of that firm's complete patent portfolio up to year *t-1* is smaller than the average by a standard deviation of over 0.5, the technological repositioning is considered to be insignificant.

Table 2.6 reports the outcomes of a multinomial logit regression on the different levels of technological repositioning. The results of Model 1 suggest that hiring native R&D workers is positively related to the likelihood of a moderate technological repositioning, while a positive and significant relationship between the recruitment of foreign R&D workers and

[15]If a firm does not file any new patent in year t, its technological position remains unchanged.

the likelihood of a strong technological repositioning is found. Note that also a weakly significant relationship between the recruitment of foreign R&D workers and the likelihood of a moderate technological repositioning appears. However, interesting differences arise when we also account for the similarity in educational backgrounds between the recruited R&D worker(s) and firms' incumbent R&D workforce in Model 2. First, we find that the relationship between the recruitment of native R&D workers and the likelihood of moderate technological repositioning is most pronounced (both economically as well as statistically) when the educational distance between these recruits and firms' incumbent R&D workforce is large (*Low educational similarity*). Second, we now only find evidence for the existence of a positive and significant relationship between the recruitment of foreign R&D workers and the likelihood of a strong technological repositioning when the educational distance between these recruits and firms' incumbent R&D workforce is large (*Low educational similarity*). In case the educational distance between foreign R&D hires and firms' incumbent R&D workforce is small (*High educational similarity*), the recruitment of these foreign R&D workers is only significantly related to the likelihood of a moderate technological repositioning (p-value = 0.059).

— Insert table 2.6 about here —

Together, these findings confirm our intuition that the degree of "difference" between new R&D hires and firms' incumbent R&D workforce affects the extent to which they might affect the hiring firm's technological position. When considering the strong technological repositioning of a firm, it is of little surprise to find the strongest effect from hires that bring knowledge that is different both in regards to its technological as well as geographical context (i.e., foreign R&D hires for whom the educational distance between themselves and the firm's incumbent R&D workforce is large). Moreover, these findings place an important side note to the presented results regarding the positive relation between firm-level exploration and hiring foreign R&D workers for whom the similarity in educational background between themselves and the firm's incumbent R&D workforce is high. While the results reported in Table 2.4 indeed provide evidence of a positive relation between these hires and the extent to which the hiring firms explore novel technology fields from the perspective of the firm, our technological repositioning analysis suggests that this increase in exploratory activity only leads to a modest technological repositioning.

R&D hires and knowledge sourcing

In order to provide additional support for our hypotheses, we utilized the backward citations of each patent to construct an alternative measure of exploration. If it is true that foreign R&D hires are aware of different knowledge and can give access to knowledge that is *locked* within other regions (Choudhury & Kim, 2019), we expect that foreign R&D hires have a different effect on the extent to which firms draw on knowledge from previously unexplored technological and geographical areas when developing new technologies, as compared to hiring high-skilled native R&D workers. We do this by examining the technological as well as geographical novelty of the technological prior art cited by the hiring firm's subsequent patent applications. Technological prior art is considered to be *technologically* novel from the perspective of the firm when this prior art is assigned to technology classes (IPC 4-level) that have not been exploited by that firm over the past five years. Technological prior art is considered to be *geographically* novel from the perspective of the firm when the assignee of the cited prior art is located in a geographical region (country-level) that has not been exploited by that firm over the past five years. In addition, we analyze the relationship between hiring high-skilled foreign R&D workers and the extent to which technological prior art assigned to assignees situated in the countries of origin of these foreign hires gets cited by the hiring firm's subsequent patent applications. While identifying knowledge flows between different individuals and organizations is a highly complicated and controversial topic, our approach follows prior literature that has used patent citations to measure the diffusion of knowledge (e.g., Almeida & Kogut, 1999; Song et al., 2003; Peri, 2005; Agarwal et al., 2009).

We test the relationship between hiring high-skilled native and foreign R&D workers, and the exploratory character of the technological prior art cited by the firm in the development of new technologies, by running negative binomial models on the three constructed count variables: (a) the number of patent citations to technological prior art situated in previously unexploited technology classes from the perspective of the hiring firm, (b) the number of patent citations to technological prior art assigned to assignees based in previously unexplored geographical regions, and (c) the number of patent citations to technological prior art assigned to assignees based in the countries of origin of a firm's foreign R&D hires. We respectively control for the total number of cited technology classes and geographical origins in these models.[16]

— Insert figure 2.3 about here —

Figure 2.3 plots the estimated regression coefficients corresponding to the share of new native R&D hires and the share of new foreign R&D hires. The graphical presentation of these coefficient estimates indicates the existence of a strong and positive relationship between newly hired foreign R&D workers and the extent to which the hiring firm sources knowledge from (a) previously unexplored technology fields, (b) previously unexplored geographical regions, and (c) the countries of origin of its newly hired foreign R&D workers. Moreover, Wald tests indicate that both coefficients are significantly different from each other in each of the three negative binomial models (p-value ≤ 0.05). In short, this evidence suggests that firms draw on more diverse solution sets and might access previously unexploited knowledge through the recruitment of high-skilled foreign R&D workers.

2.4.4 Robustness checks

Coarsened exact matching. All presented results are robust against using a matched subsample by means of coarsened exact matching, as presented in Table 2.7. This nonparametrical matching method segments the joint distribution of firm characteristics into a finite number of strata using cut points for each characteristic, thereby resulting in a subsample of similar treatment and control firms belonging to the same strata while discarding others

[16] In correspondence with our main specification (see Section 2.3.3), these industry and year fixed-effect negative binomial regressions also include controls for educational diversity, geographical diversity, firm size, R&D intensity, patent stock (5y), and the share of international co-applied patents.

(Blackwell et al., 2009; Iacus et al., 2012). The purpose of this analysis is to exclude the possibility that our results are driven by observed firm level characteristics, such as, for example, a higher innovation prowess. To do this, we consider each firm-year observation in which a new foreign R&D worker is hired as a treatment observation (642 observations) and matched it with firm-year observations of firms that never hired a foreign R&D worker over the analyzed time window, but are otherwise very similar with respect to size, industry, R&D recruitment and intensity, and exploratory activity. More specifically, we match "treated" firm-year observations to "control" firm-year observations based on the following characteristics (cut points in parentheses): (1) number of employees (< 100 (small); 100–500 (medium); > 500 (large)), (2) R&D intensity (< 0.10; 0.10–0.25; > 0.25), (3) year, (4) industry, (5) number of exploratory patents over the last five years (ln), and (6) whether the firm has hired a new R&D worker in that year or not (dummy).[17] Jointly applying these six criteria, we exactly match 50.3% of our "treated" firm-year observations (323) with 625 "control" firm-year observations. As noticed, applying these strict matching criteria is done at the cost of the number of matched treated firm-year observations.

— Insert table 2.7 about here —

Additional robustness checks. In order to exclude the likelihood that our results are purely driven by choices of sampling and definition of our variables, we conduct a series of additional robustness checks. To address the concern that our results may be driven by a small number of large firms, we exclude the 5% largest firms from our sample. This does not change our results. In addition, we rule out that our findings are mechanically driven by firms with low patenting activity, as our results are robust when dropping the firms with the 10% lowest patenting activity (Table 2.11). Furthermore, the results concerning the similarity in educational background between new R&D hires and firms' incumbent R&D workforce are robust when applying a less fine-grained educational classification (e.g., 6-digit level) and disregarding the level of these workers' tertiary education and only focussing on the field of education (Table 2.10. Likewise, all results are robust against including a control variable

[17]This is by definition always 1 for our matched sample.

that accounts for the share of patents developed by firm i with the involvement of foreign inventors in year t to proxy for foreign ownership and international collaboration, which can be argued to be another source of distant knowledge (Table 2.9). Moreover, all results are robust against alternative definitions of the main dependent variable. First, in order to control for differences in the quality and value of the exploratory patents filed by a firm, we weigh each exploratory patent by the number of subsequent patent citations it receives. In line with prior studies, we apply a fixed five-year citation window in order to obtain a comparable citation-window across all exploratory patents. Hence, the variable *Citation Weighted Exploratory Patents* accounts for the number of citation-weighted exploratory patents filed by firm i in year t. All results are robust against using this citation-weighted version of our main dependent variable (see Table 2.8). Second, we define exploration using a five-year window. In this case, a technology class is considered as novel-to-the-firm in application year t if the firm has not patented in the relevant technology domain over the past five years (*t-5* to *t-1*). All results are robust. Third, the results are robust against using *Exploratory technology fields* as a dependent variable instead of *Exploratory patent count*.[18] This variable is a count of the number of exploratory technology classes in which firm i has been active in year t. To clarify, in case firm i applies for three patents in year t and one of these patents is situated in two technology fields that are novel from the perspective of the firm, the variable *Exploratory technology fields* will be equal to two while the variable *Exploratory patent count* will be equal to one. Another concern might be that foreigners are, on average, more skilled than natives. While we do not have any measure to directly compare the skills and associated performance of natives and foreigners, we expect that these will be reflected in the wages paid by their employer. To rule out that foreigners are, on average, more skilled, we compare the hourly wages of newly hired foreigners and native R&D workers, using a simple t-test. The results reveal that newly hired foreign R&D workers earn, on average, less than their native counterparts (321.85 DKK vs. 335.75 DKK per hour $t = 4.01$; $p < 0.001$), which does not provide evidence for a skill premium of

[18]While controlling for the total number of technology fields in which firm i is active in year t.

foreign R&D hires. We further re-estimate the models, using a Poisson maximum likelihood estimator, which confirms the validity of our results (Table 2.12). To separately evaluate how incumbent foreign R&D workers affect exploration, we divide the baseline group into foreign and native incumbent R&D workers and only use native R&D workers, as a baseline. All results are robust, and do not reveal any effects of incumbent foreign R&D workers on exploration (Table 2.13).

2.5 Discussion & Conclusion

Motivated by the increasing technological specialization of individual inventors (Jones, 2009; Toh, 2014) and the pressing need for firms to access distant knowledge to remain competitive over time (Nelson & Winter, 1982; March, 1991; Rosenkopf & Almeida, 2003), this study investigates the effects of hiring high-skilled foreign R&D workers on firms' exploratory activity. Examining a sample of 376 Danish R&D active firms over the period from 2001 to 2013, we showed that hiring foreign R&D workers affects the exploratory character of the subsequent inventive output of the firm more positively than does the recruitment of native R&D workers. We argue that knowledge brought by foreign hires is likely to be more diverse vis-à-vis the knowledge brought by local R&D hires, for two reasons. First, foreign R&D workers are more likely to be educated in different fields and are, therefore, specialized in different technologies. Second, the knowledge and insights brought by foreign R&D workers are more likely to differ with regard to the context in which they were acquired', and are, therefore, shaped by distinct cultural backgrounds and country-specific attributes. Hence, we propose that hiring foreign R&D workers may provide firms access to a broader set of novel ideas, insights and problem-solving perspectives, as compared to the recruitment of native R&D workers, and, therefore, may spur firm-level exploration to a higher extent.

Moreover, we analyzed the conditions under which the recruitment of R&D workers can most effectively foster firm-level exploration, by exploiting the heterogeneity of their educational backgrounds and geographical origins to account for their relative distance, vis-a-vis the hiring firm's incumbent R&D workforce. We found that the effect of the recruitment of foreign R&D workers on firms' exploratory activity is significant when these foreign R&D workers are hired from geographical backgrounds that are represented within a firm's incumbent R&D workforce to a relatively lesser extent. Further, we showed that – in contrast to native R&D hires – hiring foreign R&D workers leads to increased levels of firm-level exploration, even when the similarity between the educational backgrounds of these new hires and firms' incumbent R&D workforce is high. This lends support to our argument that foreign R&D workers can provide firms access to knowledge geographically distant knowledge, which can foster exploration.

Nonetheless, we remark that the exploration of novel technology fields does not necessarily go hand in hand with significantly changes in a firm's technological position. While our main results indeed provide evidence of a positive relation between firm-level exploration and hiring foreign R&D workers, for whom the similarity in educational background between themselves and the firm's incumbent R&D workforce is high, the outcomes of our additional analysis focusing on technological repositioning suggest that the recruitment of such foreign R&D workers only leads to a modest technological repositioning. A positive and significant relationship between the recruitment of foreign R&D workers and the likelihood of a strong technological repositioning is only found when the educational distance between these recruits and firms' incumbent R&D workforce is large.

Together, the outcomes of our study reveal a few insightful managerial implications as they draw attention to the conditions under which the recruitment of foreign R&D workers can increase the exploratory character of the inventive output of the hiring firm. Hiring foreign R&D workers is shown to be an effective means of accessing new and distant pieces of knowledge: overall, the recruitment of foreign R&D workers is shown to foster the exploration of novel technology fields to a significantly higher extent than does hiring native R&D workers. Nonetheless, we showed that the current knowledge stock of the hiring firm and the composition of its incumbent R&D workforce play an important role in this context. First, we found that only the recruitment of foreign R&D hires originating from geographical backgrounds that are not yet, or to a lesser extent, represented within the hiring firm's R&D workforce is related to a significant positive increase in firm-level exploration. Continuously hiring foreign R&D workers from the same geographic location is more likely to result in redundancies of knowledge and skills, which is shown to affect the exploration of novel technology fields to a lesser extent. Second, our results suggest that, when the educational distance between these foreign R&D hires and firms' incumbent workforce is too large, firms might still face certain barriers in absorbing the knowledge embedded in these foreign R&D workers, and the relationship between the recruitment of such foreigners and firms' exploratory activity is found to be less significant.

While our results are robust against a wide set of alternative specifications (see section 2.4.4), our study is not without limitations. Most importantly, a firm's decision to hire foreign R&D workers is not random, and the same is true for a foreigner to accept a job in a different country. In spite of our robustness checks, we cannot entirely rule out that our results are (partially) driven by unobservable characteristics that affect hiring foreigners, as well as the development of exploratory technologies. In addition, our analysis is conditional on firms that patent regularly. Therefore, we are only able to make inferences to a small proportion of firms, since we are not accounting for factors influencing a firm's decision to patent. This poses a great opportunity for future research to take up this challenge and further investigate questions regarding the match between firms and foreigners as well as heterogeneous firm effects of hiring high-skilled foreign R&D workers.

Despite these limitations, we are confident that our study contributes to the existing literature in two ways. First, our study adds to extant research on firm-level exploration by highlighting that the relationship between firm-level exploration and high-skilled R&D recruitment does not depend only on the technological content of newly hired R&D workers' knowledge, but also on the geographical context in which they acquired this knowledge. Second, the outcomes of our analyses contribute to the broad literature on immigration and innovation by showing how native and foreign R&D hires differently affect firms' innovation and exploration processes, and emphasizing the argument that foreign R&D hires are not merely substitutes for native R&D hires.

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Tables

Table 2.1: Summary statistics

Variable	Mean	Std. Dev.
Exploratory activity (dummy)	.176	.380
Exploratory patent count	.338	1.066
Non-exploratory patent count	2.012	8.168
New native R&D hires	5.794	2.077
New foreign R&D hires	.382	1.310
Total employees	461.94	974.96
Share new native R&D hires	.192	.257
Share new foreign R&D hires	.012	.058
Educational dissimilarity vs. R&D workforce:		
- New native R&D hires	.905	.509
- New foreign R&D hires	1.061	.508
R&D intensity	.124	.150
Employees (ln)	5.070	1.506
Share of int. co-applied patents 5y	.115	.245
Patent stock 5y (ln)	1.257	1.302
Pre-sample explor. pat. stock (ln)	1.127	1.036
Dummy pre-sample techn. explor. activity	.702	.458
N	3,732	

Table 2.2: Correlation table ($n = 3,732$)

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1)	Share new native R&D hires	1.000										
(2)	Share new foreign R&D hires	0.003	1.000									
(3)	Educational diversity	-0.291	-0.041	1.000								
(4)	Geographical diversity	-0.124	0.017	0.319	1.000							
(5)	R&D intensity	0.046	-0.003	0.250	0.093	1.000						
(6)	Employees (ln)	-0.082	-0.022	0.370	0.135	-0.438	1.000					
(7)	Patent stock 5y (ln)	-0.041	0.008	0.328	0.119	0.008	0.358	1.000				
(8)	Share of int. co-appl. pat. 5y	-0.005	-0.005	0.208	0.068	0.041	0.106	0.362	1.000			
(9)	Pre-sample explor. pat. stock (ln)	-0.109	0.003	0.382	0.127	-0.076	0.448	0.679	0.255	1.000		
(10)	Dummy pre-sample explor. activity	-0.111	-0.011	0.182	0.050	-0.133	0.245	0.348	0.168	0.709	1.000	
(11)	Dummy explor. activity *t-1*	0.022	0.022	0.171	0.047	-0.023	0.233	0.530	0.152	0.379	0.167	1.000

Table 2.3: Negative binomial regression on exploratory and non-exploratory patent count

	(1) Exploratory Pat. Count	(2) Non-Exploratory Pat. Count
R&D worker shares:		
Share new native R&D hires	0.321	0.544^{**}
	(0.243)	(0.247)
Share new foreign R&D hires	2.303^{**}	1.259
	(1.003)	(0.866)
Control variables:		
Educational diversity	0.400^{**}	0.513^{**}
	(0.192)	(0.216)
Geographical diversity	0.023	0.312
	(0.407)	(0.324)
Employees (ln)	0.087^{*}	0.001
	(0.049)	(0.046)
R&D Intensity	-0.812	0.311
	(0.550)	(0.502)
Patent stock 5y (ln)	0.449^{***}	1.082^{***}
	(0.058)	(0.045)
Share of int. co-appl. pat.	-0.235	0.219
	(0.199)	(0.149)
Lag. pat. and pre-s. contr.	Incl.	Incl.
Industry FE	Incl.	Incl.
Year FE	Incl.	Incl.
Log lik.	-2066.128	-3150.743
N	3,732	3,732

Standard errors in parentheses. Standard errors are robust and clustered by firm. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.4: Negative binomial regression on exploratory and non-exploratory patent count: educational and geographical similarity of R&D hires

	(1) Explor. Pat. Count	(2) Non-Explor. Pat. Count	(3) Explor. Pat. Count	(4) Non-Explor. Pat. Count
<u>*R&D worker shares:*</u>				
Share new native R&D hires	0.322	0.544**		
	(0.243)	(0.247)		
– *High educational similarity*			0.084	0.822***
			(0.328)	(0.315)
– *Low educational similarity*			0.562**	0.145
			(0.286)	(0.258)
Share new foreign R&D hires				
– *High geographical similarity*	3.479	3.984*		
	(3.874)	(2.214)		
– *Low geographical similarity*	2.229**	0.857		
	(1.042)	(0.957)		
– *High educational similarity*			2.114**	1.217
			(1.077)	(1.310)
– *Low educational similarity*			2.638	1.187
			(1.629)	(1.116)
Control variables	Incl.	Incl.	Incl.	Incl.
Lag. pat. and pre-sample contr.	Incl.	Incl.	Incl.	Incl.
Industry FE	Incl.	Incl.	Incl.	Incl.
Year FE	Incl.	Incl.	Incl.	Incl.
Log lik.	-2066.080	-3150.045	-2065.282	-3147.978
N	3,732	3,732	3,732	3,732

Note: All models include controls for *educational diversity*, *geographical diversity*, *employees (ln)*, *R&D intensity*, *patent stock 5y (ln)*, *share of international co-applied patents* and for lagged patent status and pre-sample variables; Standard errors in parentheses. Standard errors are robust and clustered by firm, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.5: Additional analysis - Difference-in-difference estimations

	(1) Logit		(2) Neg. Bin.
	Exploratory Activity	Margins (dydx)	Explor. Pat. Count
HS. Immigration Dep. Ind.	-0.127	-0.017	0.005
	(0.171)	(0.171)	(0.166)
Tax Change 2008	-0.512*	-0.069*	-0.855***
(dummy)	(0.270)	(0.270)	(0.249)
Tax Change	0.412*	0.055*	0.402*
× HS. Immigration Dep. Ind.	(0.244)	(0.244)	(0.224)
Control variables:			
Educational diversity	-0.018	-0.002	0.161
	(0.242)	(0.242)	(0.254)
Geographical diversity	0.101	0.014	0.135
	(0.487)	(0.487)	(0.593)
R&D intensity	-0.714	-0.096	-0.998
	(0.676)	(0.676)	(0.905)
Employees (ln)	0.116**	0.015**	0.164***
	(0.057)	(0.057)	(0.059)
Patent stock 5y (ln)	0.353***	0.047***	0.445***
	(0.080)	(0.080)	(0.071)
Share of int. co-appl. pat.	-0.536*	-0.072*	-0.447
	(0.282)	(0.282)	(0.319)
Lag. pat. and pre-sample contr.	Incl.	Incl.	Incl.
Industry FE	Incl.	Incl.	Incl.
Year FE	Incl.	Incl.	Incl.
Log lik.	-907.957		-1276.858
N	2,032	2,032	2,032

Note: All models include controls for lagged patent status and pre-sample variables; Standard errors in parentheses. Standard errors are robust and clustered by firm, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.6: Additional analysis - Multinomial logistic regression on technological repositioning

	(1)		(2)	
	Moderate Tech. Repos.	Strong Tech. Repos.	Moderate Tech. Repos.	Strong Tech. Repos.
R&D worker shares:				
Share new native R&D hires	0.757**	-0.138		
	(0.348)	(0.258)		
– *High educational similarity*			0.673*	-0.125
			(0.371)	(0.261)
– *Low educational similarity*			1.389**	-0.210
			(0.678)	(0.532)
Share new foreign R&D hires	2.131*	1.523**		
	(1.143)	(0.656)		
– *High educational similarity*			2.093*	0.695
			(1.146)	(0.856)
– *Low educational similarity*			1.307	4.913***
			(3.253)	(1.571)
Control variables	Incl.	Incl.	Incl.	Incl.
Lag. pat. and pre-sample contr.	Incl.	Incl.	Incl.	Incl.
Industry FE	Incl.	Incl.	Incl.	Incl.
Year FE	Incl.	Incl.	Incl.	Incl.
Log lik.	-1552.605	-1552.605	-1549.549	-1549.549
N	3,732	3,732	3,732	3,732

Note: All models include controls for the total number of patents filed by firm i in year t, *educational diversity*, *geographical diversity*, *employees (ln)*, *R&D intensity*, *patent stock 5y (ln)*, *share of international co-applied patents* and for lagged patent status and pre-sample variables; Standard errors in parentheses. Standard errors are robust and clustered by firm, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.7: Robustness check - Negative binomial regressions for matched subsample by means of coarsened exact matching

	(1) Exploratory Pat. Count	(2) Non-Exploratory Pat. Count	(3) Cit.-weight. Expl. Pat. Count
R&D worker shares:			
Share new native R&D hires	0.397	1.107*	0.977
	(0.890)	(0.595)	(1.139)
Share new foreign R&D hires	3.414**	0.106	5.878***
	(1.500)	(1.401)	(1.890)
Control variables	Incl.	Incl.	Incl.
Lag. pat. and pre-s. contr.	Incl.	Incl.	Incl.
Industry	Incl.	Incl.	Incl.
Year FE	Incl.	Incl.	Incl.
Log lik.	-410.303	-694.993	-506.613
N	948	948	948

Note: All models include controls for *educational diversity*, *geographical diversity*, *employees (ln)*, *R&D intensity*, *patent stock 5y (ln)*, *share of international co-applied patents* and for lagged patent status and pre-sample variables; Standard errors in parentheses. Standard errors are robust and clustered by firm, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figures

Table 2.8: Robustness check - Negative binomial regression on citation-weighted exploratory patent count

	(1) Cit.-weight. Expl. Pat. Count	(2) Cit.-weight. Expl. Pat. Count	(3) Cit.-weight. Expl. Pat. Count
R&D worker shares:			
Share new native R&D hires	0.316	0.317	
	(0.322)	(0.322)	
– *Small educational distance*			-0.127
			(0.427)
– *Large educational distance*			0.710*
			(0.373)
Share new foreign R&D hires	2.972***		
	(1.110)		
– *High geo. origin overlap*		2.328	
		(4.573)	
– *Low geo. origin overlap*		3.004***	
		(1.136)	
– *Small educational distance*			3.116**
			(1.462)
– *Large educational distance*			2.853*
			(1.675)
Control variables	Incl.	Incl.	Incl.
Lag. pat. and pre-sample contr.	Incl.	Incl.	Incl.
Industry FE	Incl.	Incl.	Incl.
Year FE	Incl.	Incl.	Incl.
Log lik.	-2556.103	-2556.095	-2554.332
N	3,732	3,732	3,732

Note: All models include controls for *educational diversity*, *geographical diversity*, *employees (ln)*, *R&D intensity*, *patent stock 5y (ln)*, *share of international co-applied patents* and for lagged patent status and pre-sample variables; Standard errors in parentheses. Standard errors are robust and clustered by firm, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

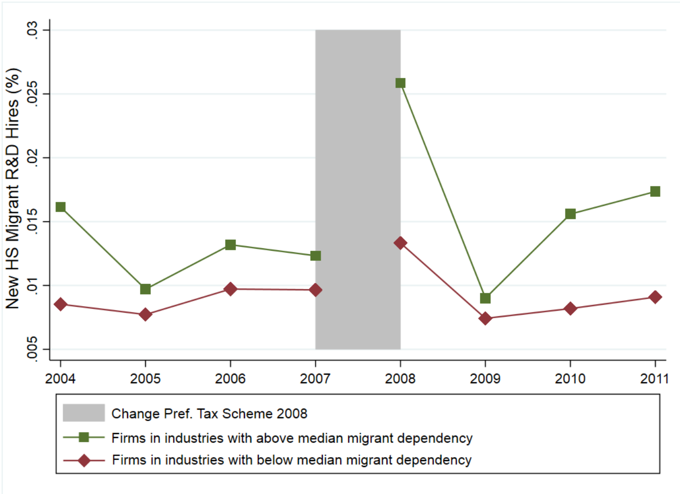

Figure 2.1: This graph presents the share of new high-skilled foreign R&D hires in a firm's R&D workforce in the period before and after the 2008 tax change.

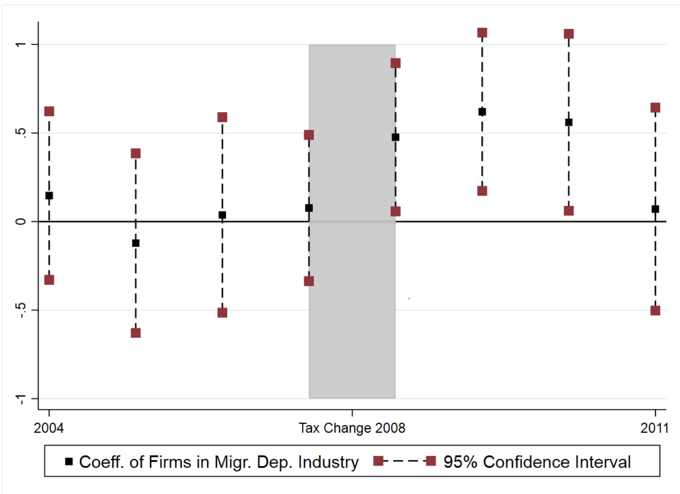

Figure 2.2: Estimated impact of the 2008 tax change on firms' exploratory patent count for firms operating in industries relying to a relative large extent on foreign R&D workers versus firms situated in industries relying to a lower extent on foreign R&D workers, in the years before and after the 2008 shock. The reported coefficients present the interactions between the high-skilled immigration dependent industry dummy and the different year dummies (dynamic difference-in-difference set up) resulting from our negative binomial regression.

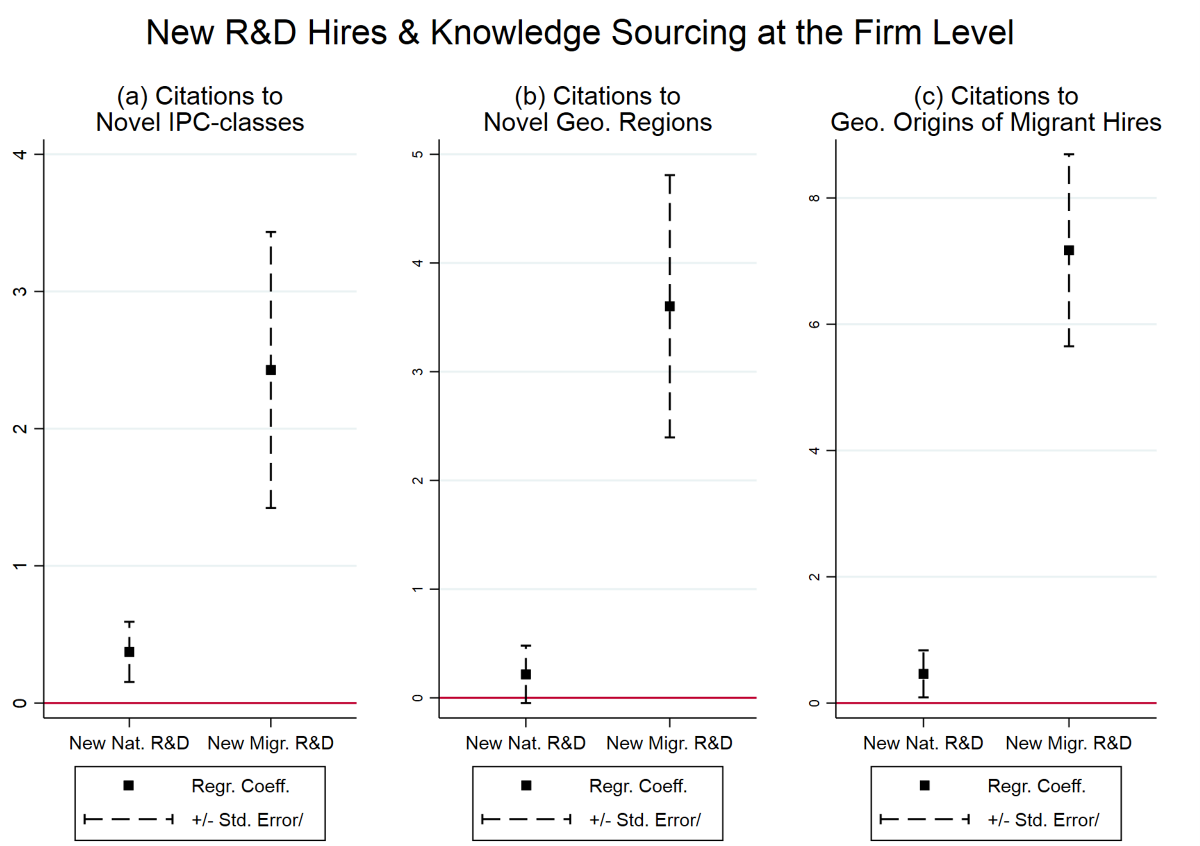

Figure 2.3: Estimated impact of the share of newly hired high-skilled native and foreign R&D workers on (a) the count of patent citations to technological prior art situated in previously unexploited technology classes from the perspective of the hiring firm, (b) the count of patent citations to technological prior art assigned to assignees based in previously unexplored geographical regions, and (c) the count of patent citations to technological prior art assigned to assignees based in the countries of origin of a firm's foreign R&D hires. The reported coefficients present the coefficients of the the share of newly hired high-skilled native and foreign R&D workers resulting from industry and year fixed-effect negative binomial models on the constructed count variables, while respectively controlling for the total count of technology classes and geographical origins cited in a given year, educational diversity, geographical diversity, firm size, R&D intensity, patent stock (5y), and the share of international co-applied patents.

Table 2.9: Robustness check - Foreign inventors

	(1) Expl. Pat. Count	(2) Expl. Pat. Count	(3) Expl. Pat. Count
R&D worker shares:			
Share new native R&D hires	0.321	0.321	
	(0.242)	(0.242)	
– *Small educational distance*			0.084
			(0.328)
– *Large educational distance*			0.562**
			(0.283)
Share new foreign R&D hires	2.301**		
	(1.002)		
– *High geo. origin overlap*		3.475	
		(3.872)	
– *Low geo. origin overlap*		2.228**	
		(1.042)	
– *Small educational distance*			2.114**
			(1.076)
– *Large educational distance*			2.637
			(1.628)
Control variables:			
Share patents with foreign inv.	0.022	0.021	0.010
	(0.280)	(0.280)	(0.278)
Educational diversity	0.400**	0.401**	0.417**
	(0.191)	(0.191)	(0.196)
Geographical diversity	0.021	-0.009	0.016
	(0.407)	(0.405)	(0.407)
Employees (ln)	0.087*	0.086*	0.095**
	(0.049)	(0.049)	(0.048)
R&D Intensity	-0.813	-0.818	-0.743
	(0.549)	(0.550)	(0.553)
Patent stock 5y (ln)	0.448***	0.448***	0.448***
	(0.059)	(0.059)	(0.059)
Share of int. co-appl. pat.	-0.249	-0.253	-0.232
	(0.289)	(0.287)	(0.287)
Lag. pat. and pre-sample contr.	Incl.	Incl.	Incl.
Industry FE	Incl.	Incl.	Incl.
Year FE	Incl.	Incl.	Incl.
Log lik.	-2066.123	-2066.075	-2065.281
N	3,732	3,732	3,732

Note: All models include controls for *educational diversity*, *geographical diversity*, *employees (ln)*, *R&D intensity*, *patent stock 5y (ln)*, *share of international co-applied patents* and for lagged patent status and pre-sample variables; Standard errors in parentheses. Standard errors are robust and clustered by firm, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.10: Robustness check - Redefinition educational distance

	(1) Expl. Pat. Count
R&D worker shares:	
Share new native R&D hires:	
– *Small educational distance*	0.044
	(0.311)
– *Large educational distance*	0.688**
	(0.305)
Share new foreign R&D hires:	
– *Small educational distance*	2.162**
	(1.012)
– *Large educational distance*	2.713
	(1.897)
Control variables:	
Educational diversity	0.442**
	(0.200)
Geographical diversity	0.026
	(0.406)
Employees (ln)	0.094*
	(0.049)
R&D Intensity	-0.737
	(0.555)
Patent stock 5y (ln)	0.448***
	(0.059)
Share of int. co-appl. pat.	-0.232
	(0.202)
Lag. pat. and pre-sample contr.	Incl.
Industry FE	Incl.
Year FE	Incl.
Log lik.	-2064.688
N	3,732

Note: All models include controls for *educational diversity*, *geographical diversity*, *employees (ln)*, *R&D intensity*, *patent stock 5y (ln)*, *share of international co-applied patents* and for lagged patent status and pre-sample variables; Standard errors in parentheses. Standard errors are robust and clustered by firm, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.11: Robustness check - Drop firms with few patents

	(1) Expl. Pat. Count	(2) Expl. Pat. Count	(3) Expl. Pat. Count
R&D worker shares:			
Share new native R&D hires	0.322	0.323	
	(0.286)	(0.286)	
– *Small educational distance*			0.023
			(0.382)
– *Large educational distance*			0.668**
			(0.332)
Share new foreign R&D hires	3.217***		
	(1.108)		
– *High geo. origin overlap*		5.207	
		(4.373)	
– *Low geo. origin overlap*		3.097***	
		(1.149)	
– *Small educational distance*			3.427***
			(1.142)
– *Large educational distance*			3.120*
			(1.875)
Control variables:			
Educational diversity	0.597***	0.598***	0.624***
	(0.229)	(0.229)	(0.240)
Geographical diversity	-0.298	-0.349	-0.310
	(0.491)	(0.497)	(0.488)
Employees (ln)	0.112*	0.111*	0.123**
	(0.060)	(0.060)	(0.060)
R&D Intensity	-0.457	-0.464	-0.361
	(0.638)	(0.639)	(0.644)
Patent stock 5y (ln)	0.466***	0.466***	0.465***
	(0.070)	(0.070)	(0.070)
Share of int. co-appl. pat.	-0.221	-0.229	-0.211
	(0.211)	(0.207)	(0.213)
Lag. pat. and pre-sample contr.	Incl.	Incl.	Incl.
Industry FE	Incl.	Incl.	Incl.
Year FE	Incl.	Incl.	Incl.
Log lik.	-1675.501	-1675.395	-1674.316
N	2474	2474	2474

Note: All models include controls for *educational diversity*, *geographical diversity*, *employees (ln)*, *R&D intensity*, *patent stock 5y (ln)*, *share of international co-applied patents* and for lagged patent status and pre-sample variables; Standard errors in parentheses. Standard errors are robust and clustered by firm, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.12: Robustness check - PQML regression on exploratory patent count

	(1) Expl. Pat. Count	(2) Expl. Pat. Count	(3) Expl. Pat. Count
R&D worker shares:			
Share new native R&D hires	0.491**	0.487**	
	(0.243)	(0.244)	
− *Small educational distance*			0.329
			(0.352)
− *Large educational distance*			0.668**
			(0.285)
Share new foreign R&D hires	2.580***		
	(0.946)		
− *High geo. origin overlap*		4.200	
		(3.414)	
− *Low geo. origin overlap*		2.470**	
		(0.995)	
− *Small educational distance*			2.599***
			(0.884)
− *Large educational distance*			2.688
			(1.707)
Control variables:			
Educational diversity	0.595***	0.594***	0.624***
	(0.208)	(0.208)	(0.213)
Geographical diversity	0.104	0.061	0.097
	(0.424)	(0.427)	(0.426)
Employees (ln)	0.079	0.079	0.083
	(0.055)	(0.055)	(0.054)
R&D Intensity	-1.621**	-1.627**	-1.590**
	(0.687)	(0.685)	(0.687)
Patent stock 5y (ln)	0.518***	0.518***	0.517***
	(0.062)	(0.062)	(0.062)
Share of int. co-appl. pat.	-0.390*	-0.394*	-0.389*
	(0.221)	(0.218)	(0.223)
Lag. pat. and pre-sample contr.	Incl.	Incl.	Incl.
Industry FE	Incl.	Incl.	Incl.
Year FE	Incl.	Incl.	Incl.
Log lik.	-2241.089	-2240.890	-2240.359
N	2474	2474	2474

Note: All models include controls for *educational diversity*, *geographical diversity*, *employees (ln)*, *R&D intensity*, *patent stock 5y (ln)*, *share of international co-applied patents* and for lagged patent status and pre-sample variables; Standard errors in parentheses. Standard errors are robust and clustered by firm, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2.13: Negative binomial regression on exploratory and non-exploratory patent count

	(1) Exploratory Pat. Count	(2) Non-Exploratory Pat. Count
R&D worker shares:		
Share new native R&D hires	0.321	0.544**
	(0.243)	(0.247)
Share new foreign R&D hires	2.303**	1.259
	(1.003)	(0.866)
Control variables:		
Educational diversity	0.400**	0.513**
	(0.192)	(0.216)
Geographical diversity	0.023	0.312
	(0.407)	(0.324)
Employees (ln)	0.087*	0.001
	(0.049)	(0.046)
R&D Intensity	-0.812	0.311
	(0.550)	(0.502)
Patent stock 5y (ln)	0.449***	1.082***
	(0.058)	(0.045)
Share of int. co-appl. pat.	-0.235	0.219
	(0.199)	(0.149)
Lag. pat. and pre-s. contr.	Incl.	Incl.
Industry FE	Incl.	Incl.
Year FE	Incl.	Incl.
Log lik.	-2066.128	-3150.743
N	3,732	3,732

Standard errors in parentheses. Standard errors are robust and clustered by firm. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Beyond scientific excellence: Are internationally mobile researchers more likely to become academic entrepreneurs?

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3.1 Introduction

The value of basic research for economic growth and private innovation has long been noted (Pavitt, 1984; Mokyr et al., 2002). However, outcomes of basic research are often too far outside commercial applicability and need to be translated into marketable products (Stokes, 1997). An important channel through which this translation takes place is through the establishment of companies by faculty members, a phenomenon generally called "academic entrepreneurship" (Zucker & Darby, 2007). Despite the importance of institutional support for this type of activity (Bercovitz & Feldman, 2008), ultimately, the decision to commercialize research findings through academic entrepreneurship is made at the individual level, pursued on a discretionary base (Jain, George, & Maltarich, 2009), and depends on the consideration of a complex combination of personal and professional factors. Isolating the individual determinants of academic entrepreneurship is therefore crucial to fully understanding how to foster it.

While the general demographic characteristics and dispositions of academics have been thoroughly investigated (e.g., Siegel & Wright, 2015), scholars continue to debate the precise motivations and barriers that academics may face as well as which types of research knowledge they may be able to leverage when starting a business alongside their academic employment. In this regard, it is especially important to consider recent changes in academic careers and the trade-offs academics may face when considering activities outside their main tasks (i.e., research, teaching, applying for grants, administrative tasks). One aspect that has recently become salient in academic careers is international mobility (see Scellato, Franzoni, & Stephan, 2015). While its importance in shaping academics' careers and scientific productivity is now well established (e.g., Baruffaldi & Landoni, 2012; Franzoni, Scellato, & Stephan, 2014; Jonkers & Cruz-Castro, 2013), the relationship between international mobility and academic entrepreneurship has been largely overlooked so far (notable exceptions are Krabel, Siegel, and Slavtchev (2012); Libaers and Wang (2012); Yasuda (2015)), even though a growing literature documents the link between migration and entrepreneurship (e.g., Saxenian, 2000; Kerr, Kerr, Özden, & Parsons, 2016).

As experience in foreign contexts has become a feature of the "normal" careers of university researchers across a range of fields, we believe that understanding its impact on other activities that an academic may choose to engage in, such as entrepreneurship, warrants further investigation. Additionally, knowledge recombination theory links the mobility of individuals with the mobility of ideas, suggesting that the ability to access existing knowledge from distant sources is key for knowledge generation and creativity in general (Fleming, 2001; Hargadon & Sutton, 1997). As successful knowledge recombination is at the basis of innovation and entrepreneurship (Schumpeter, 1942), differences in experiences aggregated by individuals through international mobility could be a key component in explaining entrepreneurship. Finally, from a policy perspective, academics' international mobility weighs in importantly for the overall balance of "brain drain and brain gain." Current public policy in fact promotes bi-directional exchange of university scientists, providing grants for stays abroad for post-docs and more experienced researchers [1] as well as tax incentives for incoming scientists [2] Evaluating the overall impact of such programs on the national economy, policy-makers may want to look beyond their potential effects in terms of narrow measures of research excellence and additionally consider the impact on a broader set of academic outcomes, including entrepreneurship activities.

This paper therefore aims to understand the relationship between international mobility and academic entrepreneurship. To do so, we not only estimate differences in entrepreneurial outcomes between mobile and non-mobile academics but also account for differences in their motivations and interests in commercialization. Essential to our approach, and in contrast to previous literature, we explicitly distinguish two types of international mobility with potentially different features. First, we compare the entrepreneurial activities of two groups of

[1] `https://ec.europa.eu/research/mariecurieactions/node_enc`

[2] `AfewexamplesinEurope:Denmark(https://www.workindenmark.dk/Working-in-DK/Tax);Italy(https://www.itaxa.it/blog/en/italian-tax-incentives-for-foreign-professors-and-researchers-10-taxable-income/);theNetherlands(https://www.belastingdienst.nl/wps/wcm/connect/bldcontenten/belastingdienst/individuals/living_and_working/working_in_another_country_temporarily/you_are_coming_to_work_in_the_netherlands/30_facility_for_incoming_employees/).`

academics who are both native to the focal country but differ in their international mobility experience by distinguishing those who have spent a considerable amount of time abroad for professional reasons (*returnees*) from native researchers with limited or no international experience (*stayers*). Subsequently, we contrast the entrepreneurial activities of returnees with those of foreign academics who work in a Danish university (*immigrants*). Additionally, we explore possible mechanisms underlying the relationship between international mobility and academic entrepreneurship, such as the role of formal barriers (e.g., visa requirements), language, research orientation, and networks outside academia.

We answer our research question by exploiting a unique dataset that allows us to analyze the entrepreneurial activities of immigrant and native academics in Denmark. Within a representative sample of more than 3,400 academics employed by Danish universities in 2017, we distinguish individuals by their country of birth and their professional experiences abroad. As evidenced in this paper, there are many immigrant academics in Denmark who are working in a variety of higher education and research fields. Moreover, a sizable number of Danish-born academics who are now working in Denmark have spent extended periods working abroad, representing instances of return migration that are crucial to distinguishing the differences in entrepreneurial propensity between immigrant and native scientists.

Comparing the entrepreneurial activities of returnees and stayers, we find a positive and significant difference between these groups in terms of the likelihood of starting a company, highlighting the possible benefits of international experience. However, when comparing the two groups of internationally mobile scientists – returnees and immigrants – we find that immigrants are significantly less likely to start a company in Denmark. These differences remain robust, even after controlling for demographics, personality characteristics, and academic performance. This result strongly suggests that international mobility is positively associated with entrepreneurship; however, mobility may not be enough to overcome some barriers that immigrant academics face in starting a company in Denmark.

This paper contributes to the literature on academic entrepreneurship by investigating the relationship between international mobility and venture creation by university researchers. It distinguishes two groups of academics with international experience: returnees and immigrants. As academics' careers increasingly span different countries, it is interesting to understand how these experiences shape researchers' involvement in entrepreneurial activities, especially as these groups, while sharing some advantages of international mobility, are likely to be driven by different motivations and to face different challenges when starting a venture in their host country. This study provides one of the first attempts to distinguish the effects of different international experiences and provides a more precise measurement of the impact of international mobility than is available in the previous literature. We provide a more complete picture of academic entrepreneurship, distinguishing where people come from and the experiences that they have aggregated abroad. This approach not only helps us to enrich our understanding of the micro-foundations of venture creation in academia but also sheds new light on the effects of public policies that are related to international flows of scientists in addition to the likely barriers to a focal country's ability to reap the economic benefits of such flows in terms of academic entrepreneurship.

The remainder of the paper proceeds as follows. In Section 2, we present the current research landscape of the international mobility of scientists and develop our theoretical reasoning, including linking international mobility and academic entrepreneurship and describing possible mechanisms. Section 3 describes the data and our empirical framework, and Section 4 presents the results, including robustness checks and additional analyses. Section 5 discusses the policy implications of our study and offers suggestions for future research.

3.2 Literature Review and Hypotheses Development

Pushed by widespread agreement on the value of promoting the commercialization of knowledge and research generated at universities, academic entrepreneurship has become an important focus for both policymakers and scholars (for reviews, see Djokovic & Souitaris, 2008; Fini, Grimaldi, Santoni, & Sobrero, 2011; Siegel & Wright, 2015). The term academic entrepreneurship has often been used in the literature to indicate a wide range of activities, including other forms of university research commercialization and even broader forms of academic engagement (for a discussion about the differences and similarities between academic research commercialization and academic engagement, see Perkmann et al., 2013). In this paper, we use the narrower definition of academic entrepreneurship as "the creation of new business to commercialize knowledge developed in universities "(Fini, Lacetera, & Shane, 2016).

Within this literature, most contributions have focused on institutional environments and organizational contexts. For example, authors have analyzed the impact of various policy changes, such as the Bayh-Dole Act or the abolition of the Professor's Privilege, and the influence of specific organizational structures, such as Technology Transfer Offices and science parks (Markman, Siegel, & Wright, 2008; Phan, Siegel, & Others, 2006). However, it is important to remember that any entrepreneurial activity at the university level is influenced by the extent to which scientists are willing to engage in the active commercialization of their research results (Tartari & Breschi, 2012). For example, research has shown that the propensity to become an academic entrepreneur is positively associated with being male (Colyvas, Snellman, Bercovitz, & Feldman, 2012) and being highly productive (Stuart & Ding, 2006; Toole & Czarnitzki, 2010). Hence, it is crucial to account for individual-level antecedents of academic entrepreneurship. One important element of academic careers that has not yet received much attention in this stream of literature is international mobility; however, we believe there are several reasons why its role in determining academic entrepreneurship merits further investigation.

Looking at the more general entrepreneurship literature, we have witnessed an increasing interest in the phenomenon of immigrant entrepreneurship, particularly in the high-tech sector. Saxenian (2000) documented the presence of immigrants as founders of high-tech start-ups in Silicon Valley in the 1980s and 1990s, finding that they accounted for around 24% of founders. Anderson and Platzer (2006) reported that between 1990 and 2005, immigrants started 40% of public venture-backed companies in the US that were operating in the high-tech space. Additionally, Wadhwa, Saxenian, Rissing, and Gereffi (2007) interviewed 144 engineering and technology companies that were founded in the US between 1995 and 2005 and found that 25% had foreign-born CEOs or CTOs, while Hart and Acs (2011) found that in around 16% of the companies in their sample, at least one founder was reported as being foreign born. Moreover, researchers have also explored the role of immigrants as knowledge creators and transmitters, including their subsequent effect on growth and development. In particular, recent works have investigated the role of highly skilled migrants in diffusing knowledge across regional (Marx, Singh, & Fleming, 2015) or national borders and in influencing host-country productivity (Canello, 2016), innovative capacity (Filatotchev, Liu, Lu, & Wright, 2011; Gibson & McKenzie, 2014; Qin, 2015), and the codification and recombination of knowledge in general (Choudhury & Kim, 2018). Furthermore, the decision to migrate involves balancing relatively high risks and uncertain future returns; therefore, international mobility may indeed be seen as an entrepreneurial act in itself (Borjas, 1987; Lin, 2010; Zucker & Darby, 2007). Taken together, these results suggest that immigrants may play an important role in academic entrepreneurship.

Moving to the more specialized academic entrepreneurship literature, few studies have explored the role of international mobility specifically concerning the creation of academic ventures, and those that have done so included a variety of mobility types and contexts. Krabel et al. (2012) found that foreign-born and foreign-educated scientists at the Max Planck Institutes in Germany were more likely to start a new company than were their domestic counterparts, arguing that this result was likely due to their experience with different research methods and cultural environments. Similarly, Libaers and Wang (2012) explored whether foreign-born scientists were more active as academic entrepreneurs (they also looked into a broader notion of entrepreneurial academics, such as a greater likelihood of obtaining government grants). In a representative sample of 2,000 US academics, they found that foreign-born academics were more successful at attracting research resources but less successful at exploiting their inventions through entrepreneurship. This was mostly due to their more basic research orientation and their underdeveloped local social networks, especially networks outside academia. Yasuda (2015) explored the relationship between different types of mobility (including international mobility) regarding the likelihood of becoming an academic entrepreneur in a sample of Japanese university researchers. Drawing on opportunity recognition theory, Yasuda (2015) showed that international mobility had a positive influence on the likelihood of becoming an academic entrepreneur. Finally, while international mobility was not the key variable of interest in the study per se, in a sample of ISI Highly Cited Researchers, Trippl (2013) found no effect of either being a returnee or an expatriate on the likelihood of starting a business as an academic. Hence, the existing research has yielded conflicting results on the impact of researchers' international mobility on academic entrepreneurship.

One important element we believe will help in clarifying the relationship between international mobility and academic entrepreneurship is the distinction between groups of individuals who have experienced different types of international mobility. The first group is composed of returnees - natives of the focal country who have returned to it after spending one or more substantial periods abroad. The second group is composed of immigrants - academics who have migrated to the focal country and now work there. On the one hand, immigrants and returnees share the possibility of reaching and recombining distant knowledge thanks to their international experience. On the other hand, immigrants represent an outgroup compared to the citizens of the focal country, while returnees and stayers may have more characteristics in common with each other, such as nationality, ethnicity, and culture. To develop our hypotheses, we therefore discuss the possible relationship between international mobility and academic entrepreneurship separately for the groups of returnees and immigrants.

3.2.1 Returnees

We define returnees as individuals native to a focal country who have been internationally mobile before returning to the focal country itself. They are an interesting group to study, as their mobility has likely increased their human capital, and simultaneously, they are still likely to share important characteristics with their counterparts who have not moved outside of the country, such as ethnicity, language, and culture. Several contributions have highlighted the possible advantages of internationally mobile researchers compared to their stayer counterparts in some scientific endeavors. The reasoning behind these studies is mainly based on the relationship between the mobility of people and the mobility of ideas and that the possibility of accessing knowledge from distant sources is favorable to innovation (Fleming, 2001; Hargadon & Sutton, 1997). It can be argued that scientists' international mobility may give them access to more distant and diverse knowledge, making them more effective at problem-solving and/or generating new ideas (Berliant & Fujita, 2009; Page, 2007), especially in research-intensive (Fujita & Weber, 2004) and highly creative (Franzoni, Scellato, & Stephan, 2018) activities.

For example, several authors have explored the connection between international mobility and scientific performance. In a series of publications, Franzoni et al. (2014); Franzoni, Scellato, and Stephan (2012) explored the patterns of international mobility of around 20,000 scientists through the GlobSci Survey. They found that migrant scientists (not residing in their country of birth) outperform their colleagues who are natives to the focal country in terms of scientific performance; moreover, both foreign-born scientists and returnees have larger international research networks compared to native researchers without any international experience. Similar results for returnee academics (namely, researchers who return to their country of birth after having spent a period abroad for professional reasons) have been shown in the contexts of isolated (Gibson & McKenzie, 2014) and developing (Jonkers & Cruz-Castro, 2013; Jonkers & Tijssen, 2008) economies.

Scholars have also begun exploring the impact of international mobility on other aspects of the academic profession, namely academic engagement and commercialization. Several studies have investigated the effect of the foreign-born status of academics on their patenting activity, finding largely non-significant results (Göktepe-Hulten & Mahagaonkar, 2010; Sauermann, Cohen, & Stephan, 2010). A few contributions have also been made with respect to academic engagement in general. Edler, Fier, and Grimpe (2011) found that mobile German scientists engage in knowledge transfer activities both with firms in Germany and abroad. A similar result was reported by Trippl (2013) in a sample of ISI Highly Cited researchers.

Conversely, international experience may also create some disadvantages for internationally mobile academics who want to start their own businesses. In particular, returnees may face the loss of domestic social capital while spending time outside their home country. Li, Zhang, Li, Zhou, and Zhang (2012) discussed this challenge with regard to venture performance. In their study of Chinese returnees, they found that new technology ventures led by returnee entrepreneurs generally underperformed those led by locals. In another study in the Chinese context, Qin, Wright, and Gao (2017) found that returnees were slower to set up new ventures compared to local entrepreneurs. A broad social network that spans the boundaries of academia is vital for academics who aspire to become entrepreneurs, as the private information that is exchanged in such a network can facilitate the recognition of commercial opportunities (Stuart & Sorenson, 2007). Moreover, scientists with broader networks are better able to acquire the resources that they need to initiate the commercialization process from external sources (Shane & Stuart, 2002). This is why the loss of social capital following mobility may be detrimental for prospective entrepreneurs.

Notwithstanding such barriers, the literature links international mobility with superior scientific performance. Further, the most scientifically productive academics possess intellectual human capital with extraordinary scientific and pecuniary value (Zucker & Darby, 1996), which enables them to contribute disproportionately to innovation and growth when engaged in entrepreneurial activities. Therefore, we hypothesize the following:

> **Hypothesis (H1):** *Returnee academics are more likely to engage in entrepreneurial activities than their counterparts who lack international experience.*

3.2.2 Immigrants

The comparison between returnees and stayers provides only a limited perspective on international mobility because new immigrant researchers may display the same advantages as returnees while perhaps facing some idiosyncratic challenges. We believe that a comparison between returnees and immigrants (excluding native stayers) is meaningful because both groups share the experience (and possibly the advantages) of international mobility yet differ in terms of belonging to a particular country, which implies differences in nationality, language, and culture. In terms of similarities, both returnees and immigrants tend to outperform native stayers in terms of scientific productivity. Stephan and Levin (2001) found that foreign-born and foreign-educated scientists are overrepresented in the US among those scientists making exceptional contributions, including being elected to the National Academy of Sciences. Borjas and Doran (2012) showed that Russian mathematicians who emigrated to the US after the collapse of the Soviet Union are more productive than their American counterparts, and Gaulé and Piacentini (2013) found a similar result for Chinese PhD students employed in US chemistry departments. This superior performance is generally believed to result from the advantages these individuals can draw from knowledge recombination (Agrawal, Kapur, McHale, & Oettl, 2011; Saxenian, 2005) and better matching after migration (Jones, 2008). Both groups may also have an advantage when engaging in entrepreneurial activities because they can recombine distant knowledge thanks to their international experiences. The literature on highly skilled immigrant entrepreneurship has frequently highlighted that foreign-born entrepreneurs can draw from their international knowledge and experiences to start more innovative businesses (Saxenian, 2000), which places them in an advantageous position compared to their native counterparts. Moreover, immigrants are likely to be positively selected based on their entrepreneurial traits, such as being more open minded (Edler et al., 2011). Because they have gone through a migration experience, they are expected to possess certain personal characteristics that could be useful in entrepreneurial endeavors, such as being more open to new experiences.

Despite the similarities in their international experiences, immigrants differ from the returnees in important dimensions, which likely affect their entrepreneurial outcomes. Along with considering academics' differing international experiences, distinguishing the various dimensions is thereby important for gaining a better understanding of which mechanisms may drive the relationship between international mobility and academic entrepreneurship.

The local culture and language may act as barriers to entrepreneurship for immigrants. It has been found that language proficiency is one of the most important determinants of labor market success for immigrants (Borjas, 1999). For most foreign-born academics, the language of their host country may be their second (or even third) language, which may deter them from engaging with actors outside university boundaries (Lawson, Salter, Hughes, & Kitson, 2019a; Libaers, 2014), as spoken language is particularly relevant for informal face-to-face interactions (Grimpe & Fier, 2010; Link, Siegel, Bozeman, & Others, 2007). Indeed, a recent contribution by Lawson et al. (2019a) explored in detail the geographical patterns of engagement of academics in the United Kingdom, finding that foreign-born academics tend to collaborate more with international actors, while their native counterparts are more oriented toward national partners.

Furthermore, differences may be present in research orientation. A survey conducted by Sauermann et al. (2010) in the US showed that foreign-born scientists were less likely to conduct applied research than they were to conduct basic research compared to their native counterparts. This may be so, especially in the US, because researchers are attracted to the country for reasons that are related to the research environment, which may cause them to focus their energy purely on scholarly work (Libaers, 2014). This is important because it has been shown that academics who perform more applied or user-oriented research are more likely to engage in commercialization and entrepreneurial efforts (Kenney & Goe, 2004; O'shea, Allen, Chevalier, & Roche, 2005). Finally, exploiting entrepreneurial opportunities requires individuals to not only draw on their personal attributes and resources but also to mobilize their social capital to acquire the resources and expertise needed to establish their businesses (Davidsson & Honig, 2003). The network in which they are embedded determines entrepreneurs' social capital, and it is often highly dependent on the location in which they want to begin their activities (Stuart & Sorenson, 2007). Immigrant academics have smaller non-academic social networks than do natives (DiTomaso, Farris, & Cordero, 1993); therefore, they have fewer ties outside academia that may help them in the commercialization of their research (Owen-Smith & Powell, 2003; Stuart & Ding, 2006). While there is no research in this area that directly compares the networks outside academia of immigrants versus returnees, given the abovementioned barriers, we can expect the external networks of immigrants in their host country to be no more developed than those of returnees.

To summarize, while returnees and immigrants share some benefits that are associated with having international experience (such as personal traits that are more conducive to entrepreneurship and a greater ability to recombine knowledge from distant sources), immigrants may suffer from disadvantages that are idiosyncratically linked to their foreignness. We thus hypothesize the following:

> **Hypothesis (H2):** *Immigrant academics are less likely to engage in entrepreneurial activities than returnee academics.*

3.3 Empirical Framework

3.3.1 The Danish context

Our study is situated in the context of Denmark, a small European country with an advanced economy. Per the World Bank's *Ease of doing business* indicator, Denmark offers a business-friendly regulatory environment.[3] In 2020, Denmark was ranked fourth behind New Zealand, Singapore, and Hong Kong SAR (China), ahead of the US and the UK. When reviewing academic entrepreneurship rates, about 11% of our respondents reported involvement in setting up a company. This number closely resembles the academic entrepreneurship rates in other advanced economies, such as Sweden (Klofsten & Jones-Evans, 2000) and the UK (D'Este & Perkmann, 2011).

There are no differences in the rules for business registration for residents in Denmark based on their citizenship. Hence, similar rules applied to all respondents in our survey, who, as employees of Danish universities, were most likely also residents of Denmark. However, in the context of academic entrepreneurship, the public regulation of work permits could

[3] (World Bank, 2018)

affect the ability of immigrant academics to start a company while being employed at a Danish university. Most immigrant researchers stay in Denmark on academic work permits that are sponsored by their universities.[4] For European Union (EU) citizens, there are no public regulations for either having side jobs or starting up a company. For non-EU citizens, any side job (and, by extension, any start-up) must be related to their academic work at the sponsoring university.

As noted earlier, language may act as a barrier to entrepreneurship for immigrants because Danish is spoken by few immigrant academics upon entering the country. Meanwhile, Denmark consistently ranks highly in terms of its population's average English proficiency (second among non-English speaking countries in Europe according to the *English First* English proficiency index),[5] and many firms report that they use English as an official language (Sanden & Kankaanranta, 2018). Moreover, official Danish websites have increasingly become available in English, such as those dealing with the immigration authority[6] and business registration.[7] Nevertheless, with Danish remaining the official administrative language in Denmark, a lack of proficiency in that language may have hampered the entrepreneurial aspirations of immigrants during much of the period that our data covers.

3.3.2 Data and sample

We combined data from different sources to empirically assess the validity of our hypotheses. The main data source was a survey of all researchers employed at a Danish university, which was conducted in October 2017. The population includes active researchers who have conducted research work for which a Ph.D. or an equivalent degree would usually be required during the five years prior to the survey. Thus, Ph.D. students, technicians, administrative staff, and inactive researchers were excluded. A total of 4,836 faculty members responded to the survey, representing an overall response rate of 38%.[8]

[4] https://nyidanmark.dk
[5] https://www.ef.com/epi/(accessedDecember28,2020).
[6] https://nyidanmark.dk/en-GB
[7] https://danishbusinessauthority.dk/business-denmark
[8] Details on the survey design and administration can be found in the Online Appendix

Although the survey represents a cross-section of academics in Denmark in 2017, the collected data provides rich longitudinal information on the respondents' migration histories and their professional experience since the start of their careers. We reconstructed the academic career of each respondent until 2017, beginning from their career start. We then operationalized the career start as the year in which the PhD was awarded minus four years.[9] To be able to match our respondents to additional data (such as publications), we limited our sample to academics who started their careers after 1960 and before 2015 and (re-)entered Denmark before 2016.

We further included information on the academics' entrepreneurial activity and international mobility. In the case of entrepreneurial activity, we determined how many companies a researcher started and the year in which each company was established. Regarding international mobility and migration, we asked foreign-born researchers in which year they came to Denmark and to indicate the start year and duration of stays outside Denmark or their country of birth that exceeded 9 months, which is a period requiring a significant relocation (up to 10 stays, which may have happened at any time in their life). The answers to this question were censored to the category of "5 years or more"; therefore, we manually looked up the end year of the stays that fell into this category using publicly available CV information from university profiles and LinkedIn. Additionally, we asked each respondent about which country was visited and their activities abroad. This resulted in a detailed longitudinal record of the international mobility and academic entrepreneurship events of researchers across their entire careers until 2017. Additionally, the survey included other variables, such as personality traits, risk preferences, and perceptions of various aspects of academic engagement. Furthermore, we matched the survey data to bibliographic information that was extracted from Scopus. We were able to match 84% of the survey population and 90% of the respondents to a Scopus profile, thereby adding yearly information about

[9] While this information was available from the survey for all respondents who had obtained their Ph.D. outside Denmark, we had to complement this information for those who obtained it at a Danish institution. To do so, we made use of the Danish Ph.D. database (Forskningsdatabasen) and linked the information based on name and scientific field. For unmatched respondents, we inferred their year of career start based on their first publication minus four years (or the establishment of their first research-based company minus one year).

publication output and citations to the data. The unmatched respondents included individuals who could not be matched (e.g., due to name changes or misspellings) and researchers with no publications in a journal indexed in Scopus. Finally, to assess the importance of the method biases that are often associated with surveys, such as recall bias or common source bias (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003), we triangulated our findings with measures of start-up activity derived from other sources. Specifically, we added information from the public business registry to verify the information that the respondents provided about their entrepreneurial activities.

3.3.3 Variables

To evaluate differences in the entrepreneurial activities between groups of academics with different backgrounds of international mobility, we conducted our empirical analysis on two sub-samples. The first consisted of a comparison between Danish researchers with international experience and those without. The second sub-sample consisted of internationally mobile researchers (i.e. returnees and immigrants). The definition of the dependent variable and some independent variables differed between the two sub-samples, as described in detail below. The first comparison provides insights into how a spell of international mobility changes the hazard of academics start a firm. The second comparison is core to providing insights into the effects of different types of mobility. Thus, by comparing the hazards of returnees and immigrants from the moment they enter Denmark, provides information about the effects of being foreign, and potential barriers regarding integration and local networks.

Dependent variable and time at risk

Our empirical approach relied on observing the timing of start-ups relative to researchers' careers and their international mobility histories. The binary dependent variable *StartComp* took the value 1 in the year in which a company is started while residing in Denmark and 0 otherwise. Our data did not allow us to determine in which country an academic started a firm in a given year, only their country of residence at that point in time. However, in the context of our survey, we assumed that firms that started after returning from abroad or moving to Denmark would also be located in the host country and considered only the years spent in Denmark as years "at risk" of starting a company in Denmark. We controlled for any company started either in Denmark or abroad prior to the mobility event. Our analysis is thereby also compatible with instances of "transnational entrepreneurship," i.e., individuals that migrate from one country to another, concurrently maintaining business-related linkages with their former country of origin"(Drori, Honig, & Wright, 2009, p. 1001). The data is right-censored in the year in which a respondent starts a company or in 2017, which is the end of our sampling period. We first compared the group of native academics who started their careers in Denmark, stayers and returnees. They are considered at risk of starting a company throughout their careers, except for the periods spent abroad by the returnees. Second, we compared internationally mobile academics, namely immigrants and returnees. As we are concerned with start-ups that happen in the focal country of our study, Denmark, we only considered companies begun after either immigrating to Denmark (immigrants) or after the first stay abroad (returnees). Figure 1 illustrates the variable definitions through three stylized scientist careers.

— Insert Figure 3.1 —

The first part of the figure refers to the sub-sample of natives. It depicts 20 years of the careers of a returnee and a stayer. Both started their careers in the same year. The number of years at risk increased by 1 for each year a respondent stayed in Denmark. For the stayer, the years at risk also reflected his academic age. The returnee stayed abroad in the 6th and 7th year of her career. Thus, starting in year eight of the returnee's career, the prior international mobility dummy will take the value 1. Further, during her stay abroad, the returnee is not considered at risk of starting a company in Denmark. This means that the count of years at risk will not increase, and any firms started during this period will be assumed to be started abroad and therefore not be considered relevant for the outcome variable.[10] Consequently, her first relevant company was started in 2013. Combined, the length of her stay abroad and her years of being at risk in Denmark amount to her academic age. In contrast, the stayer is considered at risk for his entire career, and consequently, his first company in year 6 is relevant for the dependent variable.

The second part of Figure 1 exemplifies the careers of a returnee and a foreigner. Notably, the time at risk is now measured after the mobility event. In this comparison, the returnee is only considered at risk once she returns to Denmark at an academic age of eight years. The immigrant academic starts being at risk once she enters Denmark. Hence, the risk start may happen at different career stages. Companies started prior to risk start are not considered for the dependent variable but are considered as a control for prior entrepreneurship experience.

Explanatory variables

Our estimations included variables that relate to mobility status and international experience of the different groups of academics. For the first part of our analysis, in which we compare stayers and returnees, we included the dummy variable *PrevAbroad*, taking the value 1 for returnees after their return and 0 otherwise. Hence, returnees were considered equivalent to stayers prior to their stay abroad. We also ran an alternative specification, where instead of including a dummy for prior international experience, we included the cumulative number of years spent abroad (*YearsAbroad*). In the second part of the analysis, we included the dummy variable Immigrant taking the value 1 for an immigrant academic when comparing returnees and immigrants.

Control variables

One set of control variables was included to account for differences in the time of being at risk of setting up a company. How the relevant time related to academic age differed between mobility groups. For the comparison of stayers and returnees, our main control was the variable *YearsAtRisk*, which counts the number of years in which an academic was present in Denmark. For returnees spending long periods abroad, there was a large divergence

[10] There was a total of 7 instances of returnees reporting a start-up while being abroad.

between academic age and *YearsAtRisk*. This problem was addressed in the alternative specification, where we included the cumulative number of years spent abroad (*YearsAbroad*) instead of the dummy variable for prior mobility. Similarly, for the comparison of returnees and immigrants, we counted the number of years elapsed since an immigrant academic entered Denmark or a returnee re-entered the country (*YearsAtRiskPost*). Considering that immigrants and returnees might have come to Denmark at different career stages, we controlled for their academic age upon (re-)entry either as an additional control variable (*AcadAgeEntry*) or by including a full set of academic age dummies.

Another control variable relevant for the comparison of immigrants and returnees considered possible instances of pre-mobility entrepreneurship. Hence, we included a dummy variable *Prior firm*, taking the value 1 if an academic had been involved in a start-up that happened before the mobility event and 0 otherwise. The variable applied to any start-up established before an immigrant moved to Denmark or, in the case of returnees, before their re-entry into Denmark after their stay abroad.

Common to all our specifications, a third set of variables was included that has been shown to be related to academic entrepreneurship by previous studies. As prior studies showed that male academics are more likely to become academic entrepreneurs, we included a gender dummy for *Male*. The respondents' genders were determined based on their first name, using the *genderize.io* API. It was also to be expected that there would be significant differences between scientific fields regarding the commercializability of research as well as norms within the field. We therefore included dummies for scientific field. Based on the respondents' survey responses, we differentiated between six scientific fields, including Arts and Humanities, Engineering, Medical and Health, Natural Sciences, Social Sciences, and Agricultural Sciences (which serves as the baseline category). Further, the literature suggests that internationally mobile individuals may possess certain traits that might also positively influence their willingness to become entrepreneurs (Borjas, 1987; Lin, 2010; Zucker & Darby, 2007). Hence, we included controls for a set of personality characteristics to allow for separation of the effect of the experience gained abroad from the possible intrinsic predisposition of certain researchers to engage in academic entrepreneurship. *Risk tolerance* is often associated with both entrepreneurial activity and the decision to become internationally mobile. Therefore, we collected a revealed measure of risk tolerance, in which each respondent had to select a preferred gamble from six different gambling options, which differed in terms of their expected trade-offs and associated risks (Charness, Gneezy, & Imas, 2013). We further administered a set of questions to measure the Big Five personality characteristics (i.e., *Openness, Neuroticism, Conscientiousness, Agreeableness, Extroversion*), which are based on the work of Rammstedt and John (2007), who proposed a ten-item version of the Big Five Inventory. There is a large body of literature that links personality traits to entrepreneurial outcomes (for a review, see Zhao, Seibert, & Lumpkin, 2010), which shows that openness to experience is positively related to entrepreneurial intentions. Because this trait has been shown to relate to migration as well (Jokela, 2009; Otto & Dalbert, 2012), it was important to control for personality, given that some of its aspects may predict both entrepreneurial activity and international mobility.

Engaging in academic entrepreneurship is a choice that is driven by individual motivations and perceptions of the activity itself (Tartari & Breschi, 2012); thus, we further included variables about attitudes toward research commercialization. These included barriers to academic engagement (Tartari & Breschi, 2012), such as the perception that the research would not be relevant to anyone outside academia (*Lack of relevance*), as well as how important it was to commercialize their research (*Importance of commercialization*)[11]. Additionally, to elicit the extent to which the respondents were intrinsically or extrinsically motivated in their academic job, we administered a set of eight questions that referred to different types of motivations, such as salary or independence. We then conducted a factor analysis on them to ensure that the two types of motivations were orthogonal to each other (Sauermann et al., 2010).

A final set of control variables considered the researchers' scientific productivity, which in previous research was positively correlated with academic entrepreneurship (Stuart & Ding,

[11] Importance of commercialization

2006). Therefore, we included the cumulative number of publications in $t-2$ (*Cumulative Publications* $t-2$) as well as the number of publications per year in $t-1$ (Cumulative Publications $t-2$; (Azoulay, Ganguli, & Zivin, 2017). All models also included university fixed effects and a full set of year dummies.

3.3.4 Estimation

We followed recent studies to estimate the determinants of mobility (Azoulay et al., 2017; Breschi, Lissoni, & Miguelez, 2018) or entrepreneurship (Rocha & Van Praag, 2020) and employed a discrete-time proportional hazard model (Jenkins, 2005). Accordingly, we estimated for each person i at a given year the hazard h of the complementary log-log type would be:

$$h_i(t) = 1 - exp[-exp(z(t))], \tag{3.1}$$

where

$$z(t) = c(t) + \beta' X, \tag{3.2}$$

and t denotes the number of years that have elapsed from risk start until a company is started. In this specification, $c(t)$ is the baseline hazard function, and $'X$ is a vector of the explanatory and control variables, as described above. In their exponentiated form, the β coefficients reflect the hazard ratios relative to the baseline hazard. The discrete-time implementation of this specification models a discrete outcome on a year by year basis, and has the advantage that it allows the inclusion of time-constant as well as time-variant X variables. In the main specification, we log transform the years at risk variable, assuming that there are decreasing returns to time spent in Denmark. We also apply specifications in which we do not impose a functional form to the baseline hazard function, as well as exponential time and linear time for additional robustness checks (see also Breschi et al., 2018; Gaulé, 2014).

3.4 Results

3.4.1 Descriptive statistics

A summary of the characteristics of the scientists in the two sub-samples can be found in Tables 1 and 3. Table 1 presents the descriptive statistics for the native sub-sample, which contained 29,318 person-year observations for 1,583 individuals. Table 3 presents the corresponding statistics for the mobile sub-sample, composed of 12,276 person-year observations for 1,044 individuals. As the correlation matrices for the two samples show (Tables 2 and 4), the correlations between the regressors did not generally exceed 0.3 in numerical value, suggesting that our regressions do not likely suffer from multicollinearity.[12]

— Insert Table 3.1 and 3.2 about here —

— Insert Table 3.3 and 3.4 about here —

3.4.2 Main results

We estimated two sets of regression models: one for the comparison of stayers and returnees and another for comparing returnees to immigrant academics. Throughout, the outcome variable was *StartComp* - the indicator for having established a firm in Denmark in a given year. Hypothesis 1 is addressed in Table 5, which compares the two groups of native academics: stayers and returnees. Model 1 captures the association between academic entrepreneurship and international mobility in terms of the variable *PrevAbroad*, which indicates the group of returnees. In this simple comparison, returnees were at 1.9 times the risk of starting a company compared to those who did not leave the country for any significant amount of time. Model 2 shows the results after including all control variables. As expected, controlling for a number of variables commonly associated with academic entrepreneurship and with mobility somewhat reduced the estimated premium for internationally mobile academics to a factor of 1.6. Furthermore, aligned with previous findings

[12]Exceptions include the dummy and numerical measures of staying abroad (Table 2) and the publications-related measures, which are related to measures of academic age.

(Colyvas et al., 2012), male academics were more likely than females to start a company with a relative hazard ratio of 1.7. The differences between fields were less pronounced, except academics in engineering fields, who were about three times more likely to start companies than academics in agricultural science (the reference group). Personality traits had some explanatory power. In particular, we found a positive and significant effect of *openness* to experience and the opposite effect regarding *conscientiousness*. The other traits and our measure of *risk tolerance* were not significantly correlated with starting a company in our sample. Regarding different types of motivations, only *intrinsic motivation* was positive and significantly related to starting a company. This finding was somewhat surprising because setting up a company may also provide a source of additional income for academics. As expected, a positive attitude toward the commercialization of research findings had a positive and significant coefficient. A perceived *lack of relevance* of one's own research to external partners (representing a potential barrier to entrepreneurship) showed no effect. There were mixed results in terms of the importance of the researchers' publication productivity: only recent *publications per year* $(t-1)$ had any appreciable effect on setting up a company in Denmark. Finally, our estimates of university fixed effects were insignificant, indicating that differences across institutions in terms of support for entrepreneurship and the type of research conducted were less important in explaining individual-level variations between researchers.

As evident from the significant and positive coefficient of *YearsAtRisk*, the baseline annual risk of setting up a company increased across the length of time that an academic is active in Denmark. This effect may also partly reflect the general effects of academic seniority. For stayers, academic age goes one-to-one with time at risk. However, for returnees, we can partly control for this by including the length of their stay abroad (which was zero for stayers). The variable *YearsAbroad* was added to the specification in Model 3. The results demonstrated a relative hazard factor of 1.1 per year for *YearsAbroad*. With 4.5 years spent abroad on average by returnees in our sample, this is largely consistent with an overall premium for returnees of 55%, as estimated from Model (2). The remaining coefficients and their significance were largely unaffected by this extension of the model.

Overall, the regressions in Table 5 suggest a substantial difference in the entrepreneurial propensities between native academics based on their international mobility experience. Across specifications, academics with international experience showed a relative increase in the risk of starting a company in Denmark by 1.6 to 1.9 times. Moreover, the evidence in favor of Hypothesis 1 was robust in controlling for an extensive set of determinants commonly associated with academic entrepreneurship.

— Insert Table 3.5 —

Table 6 presents the results of comparing academic scientists with different types of international experience. Model 1 shows the gross difference in entrepreneurial propensities after the mobility event for immigrants as compared to returnees. The variable Immigrant takes a value of one for foreigners and zero for returnees. With a hazard ratio of 0.625, the raw comparison revealed that immigrants were about 38% less likely to start a company in Denmark. Model 2 includes all control variables. Academic age upon (re-)entry did not have a strong impact, and it did not matter whether it was included as a set of dummies (Model 2) or a linear term (Model 3). Previous entrepreneurial activity (*Priorfirm*), on the other hand, had a large positive effect on the likelihood of starting a company after the mobility event. This speaks to learning effects and to intrinsic preferences of commercializing research through venture creation. In contrast to previous estimations, there was no significant difference between men and women among mobile academics in terms of starting a company. In the previous comparison of stayers and mobile natives, gender appeared to be related to unobserved factors that affect both mobility and entrepreneurship. However, once we controlled for mobility by comparing the two mobile groups of academics, there was little difference in entrepreneurial propensity between the genders. Additionally, there was also no difference across scientific fields. The effects of personality characteristics were comparable to those in the previous set of regressions, although intrinsic motivation was no longer strongly significant. Further, control variables for scientific performance and affiliation had no significant effect. Among the variables that measure attitudes toward entrepreneurship, only the attitude toward commercialization of one's own research had a highly significant and positive effect. Overall, the results support the foreignness discount suggested by Hypothesis 2, estimating that foreigners are 38-47% less likely than returnees to start a company in Denmark in any given year.

— Insert Table 3.6 —

To illustrate the differences between the groups, we plotted the predicted hazard functions for stylized careers of scientists who only differ regarding their international experience. Therefore, we set all continuous covariates to the sample mean. The factorial variables were set at the most frequent value in the sample (i.e., male for gender, natural sciences as the scientific field, and Copenhagen University as the affiliation). Figure 2 shows the difference between stayers and returnees. As expected, the premium only arose after return, and the returnee's curve was steeper. Figure 3 shows hazard curves for a returnee and immigrant who entered Denmark at academic age 8 and resided in the country for 30 consecutive years, illustrating the large discount associated with foreignness.

— Insert Figure 3.2 and Figure 3.3 about here —

3.4.3 Potential explanations for the immigrant discount

Table 7 shows potential alternative explanations for the foreignness discount. Model 1 explores the effect of bureaucratic barriers (such as requirements for visas and work permits) on the entrepreneurial activity of internationally mobile academics. We divided the group of immigrants into those from countries with which Denmark has freedom of movement (FoM) of workers' agreements and those from countries requiring an additional work permit. Immigrants in the latter group are subject to the rules dictated by their visa, which may preclude them from holding jobs outside their main employment (which is the sponsor of their visa). We therefore expected non-FoM immigrants to be the least likely to become academic entrepreneurs. Sixty-two percent of immigrants were from EU countries, and we found that immigrants from FoM countries were 45% less likely to start a company than returnees, while there was a similar discount for non-FoM immigrants in their likelihood of becoming academic entrepreneurs.[13] This is not conclusive evidence that formal barriers do not exist in our context, but it is an indication that formal barriers cannot fully explain the difference between returnees and immigrants.

Model 2 explores the effect of language proficiency as a potential barrier to entrepreneurial and engagement activities of foreign academics (Lawson, Salter, Hughes, & Kitson, 2019b; Libaers, 2014). This possibility may be even more relevant in our context because few foreigners master the Danish language when they first arrive in the country. However, some immigrants may be in a better position to pick up the local language, particularly natives of other countries with a language similar to Danish. We therefore included a dummy variable, where 1 represented immigrants for whom their main language is a Germanic language (e.g., Austria, Belgium, Switzerland, Germany, Luxemburg, Netherlands, Iceland, Sweden, Norway, Australia, USA, Great Britain, New Zealand, Canada, Ireland) and 0 otherwise; this assumed that immigrants speaking a Germanic language are advantaged compared to immigrants speaking more distant languages in terms of interactions with the local business community. Forty-five percent of immigrant academics were from Germanic-speaking countries. Using returnees as a reference group, we again found a marginally significant discount of about 45% for immigrants from countries speaking a Germanic language and a similar difference with non-Germanic immigrants.[14] Language, therefore, does not seem to explain the difference between foreigners and returnees. As noted previously, this could reflect the high ability level of the local population to speak English and the increasing pervasiveness of English as a business language in Denmark.

A third potential explanation considered differences in research orientation that may explain lower engagement in commercialization activities of foreign academics in their host countries. The main idea was that foreign-born academics may be more focused on basic research (Libaers, 2014; Sauermann et al., 2010), which has a lower likelihood of being com-

[13] A Wald test also revealed that there was no statistical difference between the two groups of immigrants (see Table 7, Model 1).

[14] A Wald test revealed again that there was no statistical difference between the two groups of immigrants (see Table 7, Model 2).

mercialized. To test whether this applied to our sample, we classified researchers according to the *basicness* of their research interests. Traditionally, this has been done by classifying the journals in which scientists publish according to their degree of basicness. The best-known classification was developed by CHI Research in the late 1980s (Noma, 1986). To construct a measure of basicness, we employed the methodology that was recently developed by Boyack, Patek, Ungar, Yoon, and Klavans (2014), which classifies any article based on its title and abstract into the same four research levels as those of the CHI classification. We employed the open source Python code provided by Boyack et al. (2014) to classify all papers that were produced by the researchers in our sample. For each academic, we then calculated the proportion of publications in the most basic category, namely Research Level 4 (*Basicness*), prior to year t. If immigrants are indeed more likely to focus on basic research, this may explain their lower likelihood of engaging in academic entrepreneurship. When included in our main specification, the variable *Basicness* was not statistically significant, leaving the estimated coefficient of Immigrant largely unaffected (Table 7, column 3).

The final alternative explanation we explored relates to the existence of non-academic networks, as foreign-born academics may suffer from underdeveloped non-academic social networks (DiTomaso et al., 1993). We measured these in terms of co-authors at private firms after (re-)entering Denmark. For this purpose, we defined publications with authors affiliated with a Danish company (*CompCoauthors*). We further counted the cumulative number of co-authors a researcher had at Danish companies. We did not find evidence that this explains the difference between immigrants and returnees. However, it is important to keep in mind that this measure only considers networks that are realized into formal successful research collaborations.

— Insert Table 3.7 about here —

3.4.4 Robustness checks

A first concern was that the use of a survey-based, retrospective outcome variable could have caused recall bias. To ensure that our results were not driven by respondents reporting the establishment of companies with which they were not directly involved, we matched the respondents in our sample to the Danish business registry based on the researchers' names and performed manual searches on their university webpages (and LinkedIn profiles), if available to ascertain their true role in each start-up. Based on this, we refined the outcome variable to define only those respondents who were also linked to a company in the business registry as entrepreneurs.[15] In the mobile sample, the overall number of researchers who could be categorized as entrepreneurs fell from 114 to 75. The reduced number could have been caused by various involvements in setting up firms (e.g., involvements prior to formalization, employment relationships outside of board membership) or by mismatching or misspellings names. Despite the refinement of the dependent variable, the results were again qualitatively like the main results, although the significance levels dropped to around 10% for some specifications (see Appendix A1).

As a second robustness check, and aligned with the literature on high-tech entrepreneurship and STEM researcher migration, we ran the models on a sub-sample that included only STEM-field researchers. While leaving out Arts and Humanities and Social Sciences reduced the available number of respondents by about a quarter, all results remained within close range of the main results, confirming the existence of a significant immigrant discount and no overall qualitative change in the results (see Appendix A2).

As a third robustness check, we also employed nearest neighbor matching and re-ran our analyses on matched samples to make comparisons that were likely to be more balanced in terms of unobservable determinants of both international experience and academic entrepreneurship. For the first comparison, we matched stayers and returnees based on the year of career start and exactly based on gender and scientific field. This resulted in a sample

[15]We were not able to implement similar refinements in terms of the pre-move entrepreneurial experience of immigrants, which would most likely have been related to a foreign firm. The dummy variable for pre-move experience thus still relied on the survey information.

of 342 matched pairs of scientists, who were also fairly balanced based on other characteristics, except returnees, who were on average more intrinsically motivated though less well published (during their first year abroad) than stayers (see Appendix A3, Table 6). The regression results, which can be found in Appendix A3 Table 8, were largely confirmed, and the mobility premium appeared to be even larger. For the comparison between foreigners and returnees, we matched based on the year of career start, academic age at risk start, and exactly based on scientific field, gender, and prior academic entrepreneurship. This resulted in a sample of 230 matched pairs. Again, the results from the main analyses were largely confirmed, and the discount for immigrants was even larger than in the main specification.

In a further robustness check, we tackled the problem of unobserved individual heterogeneity. We therefore included individual-level random effects and ran so-called frailty models (see Appendix A4). These findings also confirmed our results. Finally, we also ran the model using non-parametric time dependence by including dummies for each year at risk. Further, we included *YearsAtRisk* as a linear and a quadratic term. As shown in Appendix A5, these choices did not affect the size and significance of our variables of interest.

3.5 Conclusions, limitations, and future research

Our analyses suggest that internationally mobile university researchers are more likely to start companies than their colleagues without experience abroad, while immigrant scientists are under-represented in knowledge-intensive entrepreneurship activities among academics who are employed in Denmark. Indeed, when we compared returnees to native stayers, the former group was between 1.6 and 1.9 times more likely to become entrepreneurs in any given year. When we compared the returnees to immigrants, the immigration discount lowered the entrepreneurship propensity to about half for the latter group. Considering that the overall rate of entrepreneurship in our sample was 11%, these are sizable effects of economic importance.

Our study assigns an important role to academic returnees as likely contributors to the local economy in terms of research-based start-ups. While return migrants have been at the center of an extensive policy discussion related to migrants returning to emerging economies (Lissoni, 2018), our results open a range of potential policy issues in the context of advanced economies as well as for academic returnees. As an important aspect of academic mobility extending beyond scientific excellence in a narrow sense, academic entrepreneurship should be considered when evaluating the merits of, for instance, public support of international postdoctoral grants or academic exchange, both of which are currently supported by the Danish government (through the Independent Research Fund Denmark).[16]

Furthermore, our analysis strongly suggests that immigrants are under-represented in knowledge-intensive entrepreneurship among academics who are employed in Denmark. Following our theoretical framework, our analysis indicates that explanations that are usually found in the literature may not be sufficient to attain an overall picture of the relationship between international mobility and academic entrepreneurship. Concerning policy regulations, we found no significant difference between immigrants with EU citizenship and those without. Language could be another potential barrier; however, we found that immigrants from Germanic-speaking countries, whose native language is arguably closer to Danish than most other languages, faced a similar discount as that of other immigrants in terms of entrepreneurial activity. Similarly, we found that research orientation was not a likely driver of the observed discount, and we could not find evidence that links to local businesses through co-authorship to explain our results.

One may question the generalizability of our results because they apply to the population of academics in a specific country, Denmark. In terms of their propensity to establish new ventures, we have shown Danish academics to be on par with academics in other countries, such as Sweden and the UK. Additionally, we found that the entrepreneurial propensity of academics in relation to their personal characteristics aligns with findings on academic entrepreneurship in other advanced economies. One limitation to the generalizability of our results could be using Denmark as the destination country for mobile academics. While

[16] https://dff.dk/

Denmark is among the top-5 OECD countries in terms of per capita spending on R&D and the country with the highest number of researchers per 1,000 employees (OECD, 2019), it may still represent a more peripheral destinations for foreign scientists compared to the UK or the US. Additionally, as discussed in our analysis, certain barriers may be idiosyncratic of countries where the main language is different from English: indeed, immigrants moving to economies with a mainly English-speaking population, notably the US and the UK, are likely to face a lower language barrier.

Other potential limitations of our results include the fact that we employed survey data. As such, we were unable to observe individuals who left Danish academia because they either became successful entrepreneurs or left the country before the survey year. Moreover, the respondents were right-censored in terms of any entrepreneurial activity or international mobility event that occurred after the survey year. Further, it is possible that the survey responses were biased toward the academics' most recent and most successful ventures. Finally, we were not able to observe where (beyond the country level) academics went while abroad. This might be important for several reasons; for instance, it would inform us about the potential entrepreneurial benefits that they gained while abroad (e.g., a stay in a Silicon Valley university could potentially create important spillovers in terms of exposure to a highly entrepreneurial environment). Moreover, because researchers do not necessarily move with the idea of starting a business, it is the appropriate environment that stimulates their entrepreneurial activities (Krabel et al., 2012), either because of peer effects (Bercovitz & Feldman, 2008) or appropriate institutional support (Clarysse, Tartari, & Salter, 2011).

Venturing outside the realm of academia, our findings largely conflicted with those of previous studies, indicating a positive immigrant premium in the broader context of highly skilled migration and entrepreneurship. We believe that there could be several reasons for this. For example, because we considered academics, who are by definition drawn from the right tail of the education distribution, we did not face differential education levels between immigrants and natives as a potential confounder of the immigrant premium. This contrasts with existing studies situated mainly in the US high-tech entrepreneurship context (Hunt, 2010). Additionally, considering the full population of academics, we avoided selection on the outcome variable (Hart & Acs, 2011).

With these caveats, our findings can still speak to a wider policy discourse. Many governments are actively incentivizing the migration of highly skilled people to their countries (OECD, ILO, & The World Bank, 2015) and anticipating large contributions to the economy as a result. The Danish government runs the Start-up Denmark program, which is a visa scheme that is intended "to allow talented entrepreneurs to relocate and grow high-impact start-ups in Denmark."[17] However, our findings suggest that immigrants face substantial barriers, which may prevent them from contributing fully to society. Actively lowering such barriers should thereby be a priority in the design of immigration policies, as it would increase the societal benefits of highly skilled immigration. As it is critical to establish the entrepreneurial effect of international mobility in greater detail, the limitations of our study open avenues for future research. Identifying whether all migration instances are equal or whether exposure to an entrepreneurial culture promotes subsequent entrepreneurship (Bercovitz & Feldman, 2008) should be a first priority. Additionally, in our analysis, we were unfortunately unable to control for different motivations for international mobility, especially regarding returnees. While international mobility research seems to believe that migration decisions are mostly based on socio-economic reasons, such as accessing better career opportunities (Franzoni et al., 2012), scholars are increasingly exploring the roles of family and cultural ties regarding their effects on return migration patterns (Lee & Kim, 2010). They may help determine who returns to their home country for reasons beyond their scientific performance. Family ties and cultural proximity transcend reasons that are related to economic mobility; thus, we expect them to have an opposite effect relative to the negative selection of returnees and to bring home some "stars" in terms of performance – who may have otherwise stayed abroad if they had only applied economic logic. Additionally, immigrants may be driven to a specific country by reasons beyond strict economic considerations, such as following a partner or choosing a country that reflects their values

[17] http://www.startupdenmark.info

and offers attractive living conditions. Future studies, especially those that employ a survey, should focus on these different motivations to understand if they may relate to academics' willingness to engage in the commercialization of their research.

Finally, it is crucial to understand in more detail which specific barriers immigrant academics face when starting up a company; therefore, future studies should include more elaborate measures of any formal or informal barriers, such as cultural or linguistic distance, or more precise measurements of the local networks that immigrants could leverage to understand local market conditions and the institutional context of starting a company. Moreover, evidence on the importance of these factors is required to guide public policy and to realize immigrants' full potential to contribute to innovation and growth in the domestic economy.

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Tables

Table 3.1: Summary statistics of native sub-sample

	N	Mean	SD	Min	Max
PrevAbroad	29,318	0.22	0.41	0.00	1.00
YearsAbroad	29,318	0.84	2.00	0.00	23.00
YearsAtRisk (log)	29,318	2.26	0.89	0.00	3.69
Male	29,318	0.68	0.46	0.00	1.00
Risk Tolerance	29,318	3.58	1.92	1.00	6.00
Openness	29,318	3.47	0.75	1.00	5.00
Neuroticism	29,318	2.38	0.75	1.00	5.00
Conscientiousness	29,318	4.20	0.61	1.50	5.00
Agreeableness	29,318	3.87	0.60	2.00	5.00
Extroversion	29,318	3.46	0.86	1.00	5.00
Extrinsic motivation	29,318	-0.12	0.77	-3.01	1.89
Intrinsic motivation	29,318	0.04	0.69	-4.58	1.18
Lack of relevance	29,318	0.08	0.27	0.00	1.00
Importance of comm.	29,318	0.42	0.49	0.00	1.00
Cum. Publications (t-2)	29,318	19.57	37.85	0.00	1061.00
Publications per year (t-1)	29,318	2.21	4.25	0.00	210.00

Table 3.2: Correlation matrix of native sub-sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) PrevAbroad	1															
(2) YearsAbroad	0.80	1														
(3) YearsAtRisk (log)	0.17	0.11	1													
(4) Male	0.09	0.09	0.11	1												
(5) Risk Tolerance	0.01	0.03	-0.04	0.10	1											
(6) Openness	0.02	0.01	-0.01	0.03	0.06	1										
(7) Neuroticism	-0.09	-0.08	-0.05	-0.13	-0.02	0.02	1									
(8) Conscientiousness	0.04	0.04	-0.02	-0.09	-0.08	0.01	-0.10	1								
(9) Agreeableness	0.02	-0.02	-0.01	-0.04	-0.03	0.01	-0.23	0.15	1							
(10) Extroversion	0	-0.01	-0.03	-0.14	0.00	0.14	-0.21	0.13	0.17	1						
(11) Extrinsic motivation	-0.01	-0.04	-0.01	-0.05	0	-0.02	0.04	0.10	-0.02	0.06	1					
(12) Intrinsic motivation	0.10	0.10	-0.02	-0.02	0.08	0.18	-0.07	0.13	0.09	0.09	0.12	1				
(13) Lack of relevance	0.00	0.00	-0.05	-0.03	-0.01	-0.05	0.09	-0.04	-0.05	-0.05	0.01	-0.07	1			
(14) Importance of comm.	0.01	0	-0.05	0.01	0.07	0.07	-0.01	0	0.07	0.04	-0.01	0.09	-0.06	1		
(15) Cum Pub. (t-2)	0.20	0.17	0.47	0.14	-0.01	-0.02	-0.07	0.01	-0.02	-0.02	-0.01	-0.03	-0.05	-0.07	1	
(16) Pub per year (t-1)	0.12	0.10	0.32	0.10	0.00	-0.02	-0.05	0.02	0.00	0.00	0.00	-0.01	-0.03	-0.05	0.74	1.00

Table 3.3: Descriptive statistics of mobile sub-sample

	N	Mean	SD	Min	Max
Immigrant	12,276	0.48	0.50	0.00	1.00
YearsAtRisk (log)	12,276	1.90	0.92	0.00	3.69
AcadAgeEntry	12,276	7.91	5.99	1.00	40.00
Prior firm	12,276	0.02	0.15	0.00	1.00
Male	12,276	0.73	0.44	0.00	1.00
Risk Tolerance	12,276	3.52	1.90	1.00	6.00
Openness	12,276	3.58	0.73	1.50	5.00
Neuroticism	12,276	2.42	0.77	1.00	5.00
Conscientiousness	12,276	4.15	0.62	1.50	5.00
Agreeableness	12,276	3.79	0.62	1.50	5.00
Extroversion	12,276	3.38	0.86	1.00	5.00
Extrinsic motivation	12,276	-0.02	0.80	-2.98	1.99
Intrinsic motivation	12,276	0.06	0.68	-3.36	1.18
Lack of relevance	12,276	0.11	0.32	0.00	1.00
Importance of comm.	12,276	0.46	0.50	0.00	1.00
Cum. publications (t-2)	12,276	29.52	51.80	0.00	1162.00
Pub per year (t-1)	12,276	3.14	5.18	0.00	133.00
Basicness	11,034	0.36	0.38	0.00	1.00
Comp. Coauth.	12,276	0.30	0.46	0.00	1.00

Table 3.4: Correlation matrix of mobile sub-sample

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
(1) Immigrant	1																		
(2) YearsAtRisk (log)	-0.20	1																	
(3) AcadAgeEntry	-0.03	-0.14	1																
(4) Prior firm	0.03	-0.05	0.19	1															
(5) Male	-0.10	0.06	0.14	0.08	1														
(6) Risk Tolerance	-0.06	-0.03	0.05	0.04	0.06	1													
(7) Openness	0.12	-0.02	0	0.01	-0.01	0.04	1												
(8) Neuroticism	0.23	-0.09	0.06	-0.04	-0.09	-0.05	0.02	1											
(9) Conscientiousness	-0.17	0.05	-0.04	0.03	-0.11	-0.02	0.05	-0.20	1										
(10) Agreeableness	-0.17	0.07	-0.11	0	-0.04	-0.02	0	-0.24	0.22	1									
(11) Extroversion	-0.10	0.01	-0.05	0	-0.13	0.06	0.06	-0.20	0.13	0.19	1								
(12) Extrinsic motivation	0.15	-0.06	-0.04	0.01	-0.10	-0.08	0.02	0.07	-0.01	-0.03	0.01	1							
(13) Intrinsic motivation	-0.16	0.03	-0.04	0.05	-0.12	0.14	0.16	-0.10	0.22	0.07	0.11	0.09	1						
(14) Lack of relevance	0.11	-0.05	-0.05	-0.05	-0.04	-0.03	-0.03	0.13	-0.11	-0.10	-0.11	0.02	-0.13	1					
(15) Importance of comm.	0.05	-0.07	-0.08	0	-0.08	0.03	0.04	-0.02	0.02	0.06	0.07	-0.01	0.06	-0.05	1				
(16) Cum Pub (t-2)	-0.09	0.31	0.31	0.06	0.13	0.01	-0.03	-0.06	0.04	0	-0.03	-0.05	-0.06	-0.06	-0.06	1			
(17) Pub by Year (t-1	-0.01	0.15	0.18	0.06	0.10	0.01	-0.01	-0.03	0.01	-0.01	0	0	-0.05	-0.04	-0.02	0.63	1		
(18) Basicness	-0.09	0	0.10	-0.02	0.06	0.06	0.03	0.02	0.05	-0.06	-0.04	-0.06	0.07	0.09	-0.03	0.07	0.02	1	
(19) Comp. Coauth.	-0.07	0.32	-0.03	0.03	0.03	-0.01	0.00	-0.02	-0.01	0.03	-0.02	-0.05	0.01	-0.03	0.06	0.33	0.28	0.06	1.00

Figures

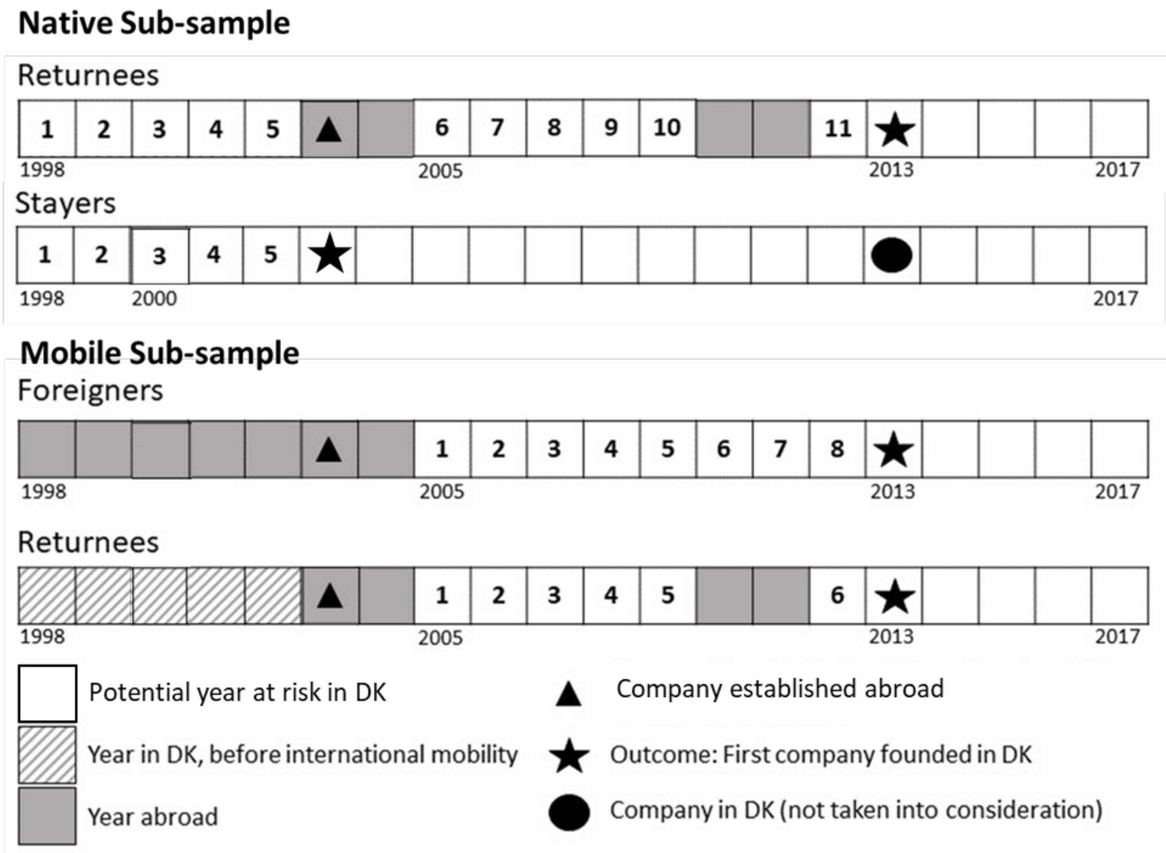

Figure 3.1: This figure illustrates how the key variables are defined in the two sub-samples. Years spent in Denmark have a white background, however not all are counted for the definition of years at risk, and relevant years are numbered. The native sub-sample, depicts 20 years of the careers of a returnee and a stayer. Both started their careers in the same year. The number of years at risk increased by 1 for each year a respondent stayed in Denmark. For the stayer, the years at risk also reflected his academic age. The returnee stayed abroad in the 6th and 7th year of her career. Thus, starting in year eight of the returnee's career, the prior international mobility dummy will take the value 1. Further, during her stay abroad, the returnee is not considered at risk of starting a company in Denmark. This means that the count of years at risk will not increase, and any firms started during this period will be assumed to be started abroad and therefore not be considered relevant for the outcome variable. Consequently, her first relevant company was started in 2013. Combined, the length of her stay abroad and her years of being at risk in Denmark amount to her academic age. In contrast, the stayer is considered at risk for his entire career, and consequently, his first company in year 6 is relevant for the dependent variable. The second part of Figure 1 exemplifies the careers of a returnee and a foreigner. Notably, the time at risk is now measured after the mobility event. In this comparison, the returnee is only considered at risk once she returns to Denmark at an academic age of eight years. The immigrant academic starts being at risk once she enters Denmark. Hence, the risk start may happen at different career stages. Companies started prior to risk start are not considered for the dependent variable but are considered as a control for prior entrepreneurship experience.

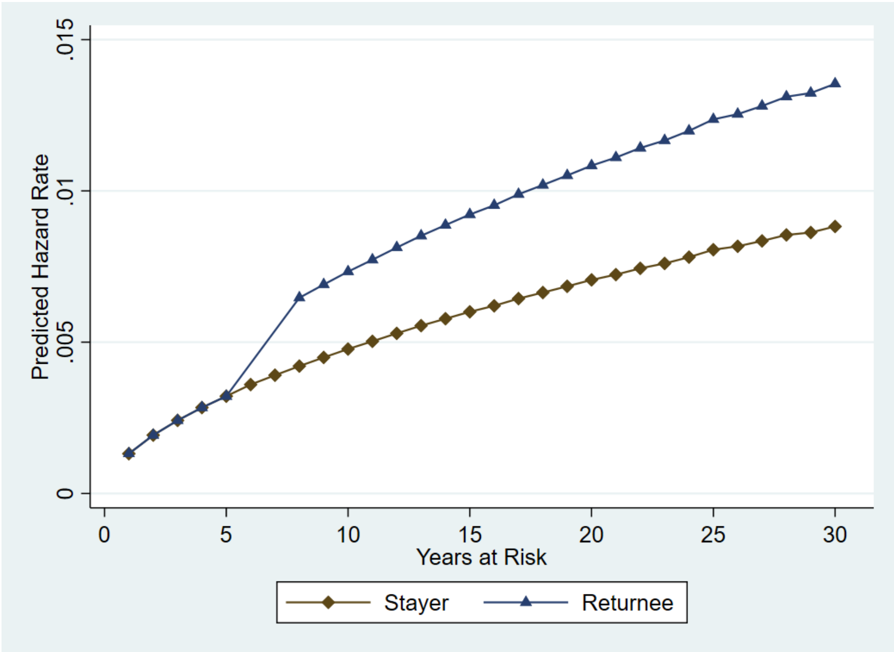

Figure 3.2: This figure shows the difference between stayers and returnees from the career start until academic age 30. The hazard for returnees changes upon return to Denmark in year 8, where the variable PrevAbroad changes from 0 to 1.

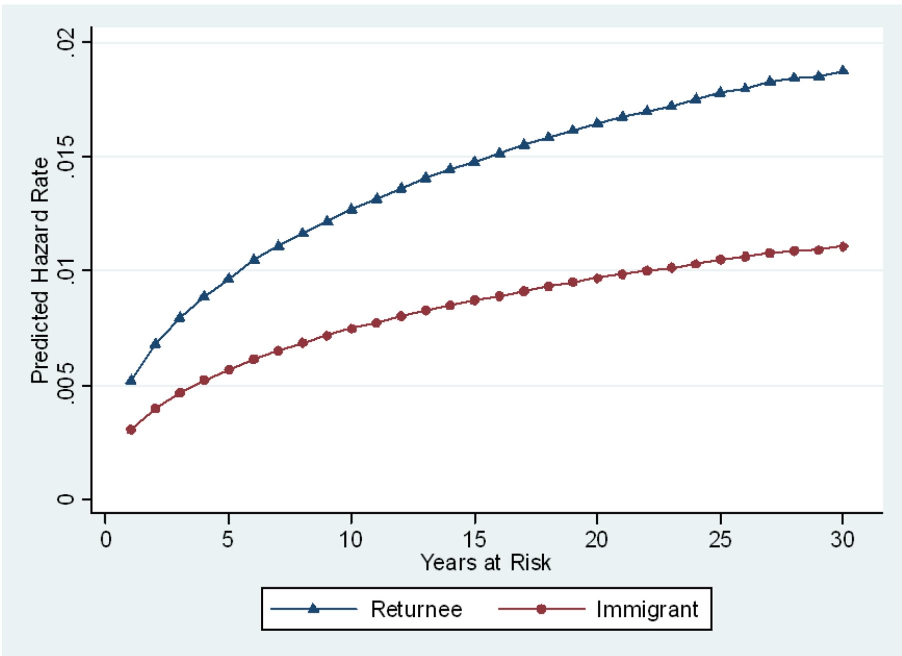

Figure 3.3: This figure shows hazard curves for a returnee and immigrant who entered Denmark at academic age 8 and resided in the country for 30 consecutive years.

Appendix

A1: Robustness Checks – Business Register

A2: Robustness Checks – STEM Fields

A3: Nearest Neighbor Matching

To tackle the concern that our results are driven by outliers and differences between the different groups, we re-run the analyses on a matched sample. Thus, for the first comparison, we find for each mobile scientist a comparable stayer, and conduct nearest neighbor matching based on career start, and exactly based on scientific field, and gender. This results in the following mean differences in the year prior to the first mobility spell for internationally mobile scientists and the corresponding matched year for stayers.

We conducted a similar procedure for the sample of mobile scientists, and conducted a nearest neighbor match based on career start, academic age at risk start, and exactly based on prior firm dummy, scientific field, and gender, in the year of first (re-)entering Denmark. This results in the differences reported below.

A4: Unobserved heterogeneity – Frailty models

Another concern with our results relate to unobserved heterogeneity on the individual level. Implications of this may be that the degree of negative duration dependence is over-estimated, and that the proportionate effect of a given regressor on the hazard rate is no longer constant and independent of the survival time (Jenkins, 2006). We therefore test the robustness of our results, by including individual-level random effects, and run so called frailty models, and assume a normal distribution of the individual level error term. Results are generally confirmed, however, effects are consistently bigger.

A5: Different time specifications

The choice of parameterizing the functional form of the hazard function may be another source of bias. Therefore, we also conducted robustness check, showing that this is not the case. In the main models, we compare the non-parametric specification with log-time. Here, we present linear as well as quadratic specification of the hazard function.

Table 3.5: Results of discrete time hazard model for the sub-sample of stayers and returnees

	Start Comp	Start Comp	Start Comp
PrevAbroad	1.876***	1.550*	
	(0.000)	(0.012)	
YearsAbroad			1.099**
			(0.002)
YearsAtRisk (log)	1.539***	1.563***	1.617***
	(0.000)	(0.000)	(0.000)
Male		1.660*	1.654*
		(0.015)	(0.016)
Risk Tolerance		1.009	1.009
		(0.826)	(0.836)
Openness		1.384**	1.397**
		(0.006)	(0.005)
Neuroticism		0.927	0.937
		(0.500)	(0.560)
Conscientiousness		0.768	0.764*
		(0.051)	(0.044)
Agreeableness		0.848	0.856
		(0.207)	(0.236)
Extroversion		1.149	1.164
		(0.165)	(0.128)
Extrinsic motivation		1.07	1.08
		(0.504)	(0.455)
Intrinsic motivation		1.504**	1.498**
		(0.001)	(0.001)
Lack of relevance		1.052	1.048
		(0.862)	(0.873)
Importance of comm.		2.912***	2.958***
		(0.000)	(0.000)
Cum. Publications (t-2)		0.998	0.998
		(0.452)	(0.424)
Publications per year (t-1)		1.030*	1.031*
		(0.015)	(0.015)
Calendar Year F.E.	Yes	Yes	Yes
Field F.E.	No	Yes	Yes
University F.E.	No	Yes	Yes
N Researchers	1583	1578	1578
N	26623	26533	26533
Log pseudolikelihood	-999.062	-934.043	-932.990

Note. Exponentiated coefficients;
p-values in parentheses, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
Standard errors are clusters on respondent level
The first calendar year with a non-zero outcome included in the model is 1984.

Table 3.6: Results of the discrete time hazard model for returnees and immigrants

	Start Comp	Start Comp	Start Comp
Immigrant	0.625*	0.529*	0.501**
	(0.023)	(0.012)	(0.004)
YearsAtRiskPost (log)	1.132	1.427**	1.299*
	(0.240)	(-0.004)	(0.018)
AcadAgeEntry			1.012
			(0.484)
Prior firm		8.304***	5.336***
		(0.000)	(0.000)
Male		1.251	1.298
		(0.434)	(0.335)
Risk Tolerance		1.07	1.057
		(0.250)	(0.310)
Openness		1.754***	1.733***
		(0.001)	(0.001)
Neuroticism		0.9093	0.882
		(0.506)	(0.381)
Conscientiousness		0.709	0.719
		(0.051)	(0.058)
Agreeableness		0.787	0.831
		(0.177)	(0.320)
Extroversion		1.091	1.089
		(0.516)	(0.505)
Extrinsic motivation		0.987	1.024
		(0.921)	(0.844)
Intrinsic motivation		0.700*	0.7651
		(0.044)	(0.131)
Lack of relevance		0.967	1.022
		(0.922)	(0.950)
Importance of comm.		3.070***	2.744***
		(0.000)	(0.000)
Cum publications (t-2)		0.998	0.998
		(0.357)	(0.184)
Publications per year (t-1)		1.013	1.02
		(0.414)	-0.187
Ac age risk start F.E.	No	Yes	No
Calendar Year F.E.	Yes	Yes	Yes
Field F.E.	No	Yes	Yes
University F.E.	No	Yes	Yes
N Respondents	1043	937	970
N	9470	8401	8692
Log pseudolikelihood	-572.094	-505.782	-523.488

Note. Exponentiated coefficients;
p-values in parentheses, *p $<$ 0.05, **p $<$ 0.01, ***p $<$ 0.001
standard errors are clusters on respondent level;
The first calendar year with a non-zero outcome included in the model is 1984

Table 3.7: Alternative Explanations

	Start Comp	Start Comp	Start Comp	Start Comp
FoM	0.543*			
	(0.023)			
Visa	0.498			
	(0.054)			
Germanic		0.551*		
		(0.037)		
Non-Germanic		0.450*		
		(0.018)		
Immigrant			0.532*	0.533*
			(0.017)	(0.013)
YearsAtRiskPost (log)	1.424**	1.405**	1.450**	1.400**
	(0.005)	(0.006)	(0.005)	(0.008)
Prior firm	8.240***	8.445***	9.083***	8.102***
	(0.000)	(0.000)	(0.000)	(0.000)
Male	1.252	1.207	1.267	1.246
	(0.432)	(0.510)	(0.414)	(0.443)
Risk Tolerance	1.07	1.066	1.077	1.069
	(0.249)	(0.290)	(0.216)	(0.254)
Openness	1.749***	1.755***	1.743***	1.748***
	(0.001)	(0.001)	(0.001)	(0.001)
Neuroticism	0.910	0.905	0.921	0.906
	(0.510)	(0.484)	(0.570)	(0.489)
Conscientiousness	0.707	0.693*	0.740	0.713
	(0.051)	(0.044)	(0.098)	(0.057)
Agreeableness	0.789	0.786	0.809	0.788
	(0.183)	(0.177)	(0.251)	(0.178)
Extroversion	1.090	1.081	1.084	1.092
	(0.521)	(0.563)	(0.549)	(0.509)
Extrinsic motivation	0.990	0.998	0.945	0.987
	(0.939)	(0.988)	(0.681)	(0.923)
Intrinsic motivation	0.699*	0.687*	0.680*	0.700*
	(0.040)	(0.036)	(0.033)	(0.042)
Lack of relevance	0.973	0.977	1.006	0.977
	(0.936)	(0.945)	(0.986)	(0.946)
Importance of comm.	3.074***	3.201***	3.427***	3.044***
	(0.00)	(0.000)	(0.000)	(0.000)
Cum publications (t-2)	0.998	0.998	0.998	0.998
	(0.373)	(0.340)	(0.291)	(0.283)
Publications by year (t-1)	1.013	1.009	1.013	1.012
	(0.415)	(0.581)	(0.416)	(0.461)
Basicness			0.891	
			(0.742)	
Comp. Coauthors				1.144
				(0.588)
Ac. age risk start F.E.	Yes	Yes	Yes	Yes
Calendar Year F.E.	Yes	Yes	Yes	Yes
Field F.E.	Yes	Yes	Yes	Yes
University F.E.	Yes	Yes	Yes	Yes
Wald test	FoM = Visa	Ge. = Non-Ge.		
	p = 0.80	p = 0.57		
N Respondents	937	936	934	937
N	8401	8381	7815	8401
Log pseudolikelihood	-505.788	-505.751	-500.159	-485.533

Note. Exponentiated coefficients;
p-values in parentheses, *p < 0.05, **p < 0.01, ***p < 0.001
standard errors are clusters on respondent level;
The first calendar year with a non-zero outcome included in the model is 1984.

Table 3.8: A1: Robustness check –business register; Native Sub-sample

	Start Comp (regist.)	Start Comp (regist.)	Start Comp (regist.)
PrevAbroad	1.338	1.120	
	(0.149)	(0.594)	
YearsAbroad			1.069
			(0.101)
YearsAtRisk (log)	1.249*	1.263	1.266
	(0.036)	(0.058)	(0.050)
Controls	No	Yes	Yes
Calendar Year F.E.	Yes	Yes	Yes
Field F.E.	No	Yes	Yes
University F.E.	No	Yes	Yes
N Respondents	1,580	1,575	1,575
N	27,220	27,128	27,128

Note. Exponentiated coefficients;
p-values in parentheses *p < 0.05, **p < 0.01, ***p < 0.001

Table 3.9: A1: Robustness check –business register; Mobile Sub-sample

	Start Comp (regist. ret)	Start Comp (regist. ret)	Start Comp (regist. ret)
Immigrant	0.619	0.528	0.445*
	(0.116)	(0.096)	(0.029)
YearsAtRisk (log)	1.078	0.955	0.936
	(0.579)	(0.794)	(0.661)
AcadAgeEntry			0.967
			(0.216)
Controls	No	Yes	Yes
Field F.E.	No	Yes	Yes
Calendar Year F.E.	Yes	Yes	Yes
AcadAgeEntry F.E.	No	Yes	No
University F.E.	No	Yes	Yes
N researchers	1,029	852	956
N	11,490	9,526	10,555

Note. Exponentiated coefficients;
p-values in parentheses *p < 0.05, **p < 0.01, ***p < 0.001

Table 3.10: A2: Robustness Checks – STEM Fields; Native Sub-sample

	Start Comp	Start Comp__1	Start Comp__2
PrevAbroad	1.823***	1.464	
	(0.001)	(0.053)	
YearsAbroad			1.078*
			(0.036)
YearsAtRisk (log)	1.455***	1.568***	1.602***
	(0.000)	(0.000)	(0.000)
Controls	No	Yes	Yes
Calendar Year F.E.	Yes	Yes	Yes
Field F.E.	No	Yes	Yes
University F.E.	No	Yes	Yes
N Respondents	1,078	1,077	1,077
N	17,360	17,338	17,338

Note. Exponentiated coefficients;
p-values in parentheses *p < 0.05, **p < 0.01, ***p < 0.001

Table 3.11: A2: Robustness Checks – STEM Fields; Mobile Sub-sample

	Start Comp (ret.)	Start Comp (ret.)	Start Comp (ret.)
Immigrant	0.561*	0.453**	0.455**
	(0.016)	(0.008)	(0.005)
YearsAtRisk (log)	1.232	1.657**	1.515**
	(0.072)	(0.002)	(0.004)
AcadAgeEntry			1.003
			(0.903)
Controls	No	Yes	Yes
Calendar F.E.	Yes	Yes	Yes
Field F.E.	No	Yes	Yes
AcadAgeEntry F.E.	No	Yes	No
University F.E.	No	Yes	Yes
N respondents	777	729	776
N	7,140	6,704	7,136

Note. Exponentiated coefficients;
p-values in parentheses *p < 0.05, **p < 0.01, ***p < 0.001

Table 3.12: A3: Nearest Neighbor Matching; Balance matched sub-sample in matched first year of going abroad

	Natives		Mobiles		Differences	
	Mean	SD	Mean	SD	D	t
PrevAbroad	0	0	1	0	1	(.)
YearsAtRisk (log)	1.82	0.75	1.54	0.82	-0.28***	(-4.26)
Male	0.71	0.46	0.71	0.46	0	(0.00)
Risk Tolerance	3.65	1.94	3.75	1.88	0.1	(-0.70)
Openness	3.49	0.76	3.52	0.76	0.03	(0.45)
Neuroticism	2.4	0.74	2.32	0.75	-0.09	(-1.57)
Conscientiousness	4.16	0.63	4.23	0.59	0.07	(1.42)
Agreeableness	3.84	0.62	3.85	0.64	0.01	(0.21)
Extroversion	3.51	0.83	3.49	0.9	-0.01	(-0.20)
Extrinsic motivation	-0.11	0.8	-0.13	0.8	-0.02	(-0.35)
Intrinsic motivation	-0.02	0.74	0.18	0.61	0.21***	(4.00)
Lack of relevance	0.08	0.27	0.1	0.3	0.02	(0.94)
Importance of comm.	0.45	0.5	0.47	0.5	0.02	(0.54)
Cum. Publications t-2	5.55	11.23	3.02	7.51	-2.53***	(-3.47)
Publications by year t-1	1.28	2.09	1.12	2.256	-0.16	(-0.98)
Observations	342		342		684	

Table 3.13: A3: Nearest Neighbor Matching; Regression Results matched native sub-sample

	Start Comp	Start Comp	Start Comp
PrevAbroad	1.911**	1.751*	
	(0.003)	(0.015)	
YearsAbroad			1.147***
			(0.000)
YearsAtRisk (log)	1.706***	1.990***	2.216***
	(0.000)	(0.000)	(0.000)
Controls	No	Yes	Yes
Calendar Year F.E.	Yes	Yes	Yes
Field F.E.	No	Yes	Yes
University F.E.	No	Yes	Yes
N respondents	681	681	681
N	10,300	10,295	10,295

Note. Exponentiated coefficients;
First year with a non-zero outcome is 1992
p-values in parentheses *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 3.14: A3: Nearest Neighbor Matching; Balance mobile sub-sample in matched first year of going abroad

	Returnees		Immigrants		Differences	
	Mean	SD	Mean	SD	D	t
Immigrant	1	0	3	0	-2	(.)
YearsAtRisk (log)	9.70	6.19	8.67	6.68	1.03	(1.72)
AcadAgeEntry	0.01	0.09	0.01	0.09	0	(0.000)
Prior firm	0.72	0.45	0.72	0.45	0	(0.000)
Male	3.81	1.9	3.37	1.86	0.45*	(2.55)
Risk Tolerance	3.56	0.73	3.7	0.7	-0.13*	(-2.01)
Openness	2.34	0.75	2.66	0.77	-0.32***	(-4.53)
Neuroticism	4.24	0.6	4.04	0.63	0.20***	(3.50)
Conscientiousness	3.83	0.61	3.65	0.66	0.17**	(2.95)
Agreeableness	3.5	0.91	3.22	0.83	0.28***	(3.46)
Extroversion	-0.13	0.82	0.09	0.81	-0.22**	(-2.86)
Extrinsic motivation	0.14	0.64	-0.03	0.77	0.17**	(2.61)
Intrinsic motivation	0.11	0.32	0.17	0.37	-0.05	(-1.62)
Lack of relevance	0.52	0.5	0.45	0.5	0.07	(1.59)
Importance of comm.	12.25	43.45	7.41	15.16	4.83	(1.59)
Cum pub. t-2	2.18	4.94	1.75	2.64	0.43	(1.17)
Observations	230		230		460	

Table 3.15: A3: Nearest Neighbor Matching; Regression Results matched mobile sub-sample

	Start Comp (ret)	Start Comp (ret)	Start Comp (ret)
Immigrant	0.409**	0.248*	0.278**
	(0.008)	(0.019)	(0.008)
YearsAtRisk (log)	1.332	1.949**	1.666*
	(0.098)	(0.010)	(0.012)
AcadAgeEntry			1.007
			(0.774)
Controls	No	Yes	Yes
Calendar Year F.E.	Yes	Yes	Yes
AcadAgeEntry F.E.	No	Yes	No
Field F.E.	No	Yes	Yes
University F.E.	No	Yes	Yes
N Respondents	456	373	418
N	3,210	2,596	2,898

Note. Exponentiated coefficients;
First year with a non-zero outcome is 2001
p-values in parentheses $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 3.16: A4: Unobserved heterogeneity; Frailty model native sub-sample

	Start Comp	Start Comp	Start Comp
PrevAbroad	2.205***	1.916***	
	(0.001)	(0.000)	
YearsAbroad			1.151***
			(0.000)
YearsAtRisk (log)	2.652***	3.559***	4.292***
	(0.000)	(0.000)	(0.000)
Controls	No	Yes	Yes
Calendar Year F.E.	Yes	Yes	Yes
Field F.E.		Yes	Yes
University F.E.		Yes	Yes
lnsig2u	4.525	6.269	7.149
	(.)	(.)	(.)
N respondents	1,583	1,577	1,578
N	26,623	26,284	26,533

Note. Exponentiated coefficients;
First calendar year is 1984 in models 1 and 3.
, and 1986 in model 2
Difference is to ensure convergence of model
standard errors are clustered on respondent level
p-values in parentheses *p < 0.05, **p < 0.01, ***p < 0.001

Table 3.17: A4: Unobserved heterogeneity; Frailty models mobile sample

	Start Comp (ret)	Start Comp (ret)	Start Comp (ret)
Immigrant	0.558*	0.529*	0.394**
	(0.030)	(0.012)	(0.005)
YearsAtRisk (log)	1.544**	1.427**	2.137***
	(0.001)	(0.004)	(0.000)
AcadAgeEntry			1.015
			(0.542)
Controls	No	No	Yes
Calendar Year F.E.	Yes	Yes	Yes
AcadAgeEntry F.E.	No	Yes	No
Field F.E.	No	Yes	Yes
University F.E.	No	Yes	Yes
lnsig2u	3.24	0.0000370	3.625
	(.)	(.)	(.)
N respondents	1,043	937	970
N	9,470	8,401	8,692

Note. Exponentiated coefficients;
First calendar year with a non-zero outcome is 1984
p-values in parentheses *p < 0.05, **p < 0.01, ***p < 0.001

Table 3.18: A4: Unobserved heterogeneity; Frailty models alternative explanations

	Start Comp (ret)	Start Comp (ret)	Start Comp (ret)	Start Comp (ret)
Immigrant			0.398**	0.400**
			(0.006)	(0.005)
FoM	0.459*			
	(0.026)			
Visa	0.291**			
	(0.006)			
Germanic		0.458		
		(0.737)		
Non-Germanic		0.316		
		(0.632)		
Basicness			0.818	
			(0.699)	
Comp Coauth.				1.226
				(0.487)
YearsAtRisk (log)	2.086***	1.885	2.141***	2.039***
	(0.000)	(0.880)	(0.000)	(0.000)
Controls	Yes	Yes	Yes	Yes
Calendar Year F.E.	Yes	Yes	Yes	Yes
Field F.E.	Yes	Yes	Yes	Yes
University F.E.	Yes	Yes	Yes	Yes
lnsig2u	3.428	2.818	3.731	3.522
	(.)	-0.929	(.)	(.)
Wald test	FoM = Visa	Ger. = Non-Ger.		
	p=0.297	p=0.408		
N respondents	970	969	968	970
N	8,692	8,672	8,663	8,692

Note. Exponentiated coefficients;
First calendar year with a non-zero outcome is 1984
p-values in parentheses *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 3.19: A5: Native sample – different specifications of hazard function

	Start Comp	Start Comp	Start Comp
PrevAbroad	1.640**	1.509*	1.494*
	(0.004)	(0.020)	(0.024)
YearsAtRisk	1.016	1.133***	
	(0.105)	(0.000)	
YearsAtRisk (sq)		0.997**	
		(0.002)	
YearsAtRisk F.E.	No	No	Yes
Controls	Yes	Yes	Yes
Calendar F.E.	Yes	Yes	Yes
Field F.E.	Yes	Yes	Yes
N Respondents	1,577	1,577	1,552
N	26,284	26,284	20,752

Note. Exponentiated coefficients;
First calendar year with a non-zero outcome is 1985
p-values in parentheses $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Table 3.20: A5: Mobile sub-sample different specifications of hazard function

	Start Comp (ret)	Start Comp (ret)	Start Comp (ret)
Immigrant	0.493**	0.514*	0.539*
	(0.008)	(0.012)	(0.023)
YearsAtRisk	1.030*	1.107*	
	(0.047)	(0.025)	
YearsAtRisk (sq)		0.997	
		(0.126)	
YearsAtRisk F.E.	No	No	Yes
AgeAtEntry F.E.	Yes	Yes	Yes
Controls	Yes	Yes	Yes
Calendar Year F.E.	Yes	Yes	Yes
Field F.E.	Yes	Yes	Yes
University F.E.	Yes	Yes	Yes
N respondents	938	938	938
N	8,414	8,414	8,075

Note. Exponentiated coefficients;
First calendar year with a non-zero outcome is 1985
p-values in parentheses $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

The effects of academic entrepreneurship on knowledge production and collaboration in academia

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4.1 Introduction

Knowledge produced in academia is often valued as a source of competitive advantage for companies and is commonly associated with economic growth (Romer, 1990; Marx & Fuegi, 2020; Arora, Belenzon, & Patacconi, 2018). Therefore, the institutions and incentives that govern academic knowledge production have long been of scholarly interest (Merton, 1973; Dasgupta & David, 1994). It is commonly argued that academic scientists are incentivized by reward and priority (Cohen, Sauermann, & Stephan, 2020; Merton, 1973). However, universities and policy makers encourage scientists to engage with industry and commercialize their research through formal mechanisms (Perkmann et al., 2013). These boundary-spanning activities are likely to affect various aspects of knowledge production in academia.

The most extreme form of boundary spanning is academic entrepreneurship. This describes an instance in which an academic commercializes their research through direct involvement in the formation of a firm (Rothaermel, Agung, & Jiang, 2007). However, this transition requires academics to not only allocate time away from research, but also to adapt to different institutional norms, such as non-disclosure, and to translate their scientific findings to commercial applicability (Sauermann & Stephan, 2013). Prior studies have looked at the effects of academic entrepreneurship on the subsequent performance of scientists. Toole and Czarnitzki (2010), for instance showed that academic entrepreneurship has negative effects on scientific knowledge production. More recently, Fini, Perkmann, and Ross (2021), studied how entering academic entrepreneurship affects the search behavior of scientists.

It is important to consider, that academic entrepreneurship can take various forms, and it is oftentimes conducted as a side activity by scientists and is temporary in nature (Perkmann et al., 2013). While Toole and Czarnitzki (2010) only considered academics leaving academia for entrepreneurship, Fini et al. (2021) focused on academics transitioning into academic entrepreneurship while maintaining their university affiliation, but they only investigated outcomes during the entrepreneurial spell. Thus, it is important to separately investigate the short- and long-term effects of scientists' entrepreneurial spells on subsequent career outcomes. Therefore, this paper asks how academic entrepreneurship affects the productivity and collaboration patterns of academic scientists, both during as well as after entrepreneurial spells. I argue that in addition to representing a unidirectional transfer of technology from academia to industry, academic entrepreneurship also affects knowledge production in academia beyond the rate of research (Rosenberg, 1982). Entrepreneurship is a particularly interesting form of engagement, as it shifts a researcher's focus towards activities beyond research. Similar to regular entrepreneurship, it leads to the accumulation of specific skills (Lazear, 2005) and provides entrepreneurs access to additional resources (Buenstorf, 2009).

I answer the above question using the Danish linked employer–employee data, which were matched with publication data from Scopus, covering the the years 1999 to 2016. I focus on academics who entered entrepreneurship between 2004 and 2008; this time period was selected because it falls in the middle of the sample. To define academic entrepreneurs, I used their role in a firm and included scientists who are classified either as being self-employed or as employers. Further, I only focused on scientists who maintained their employment at a Danish university. To define an adequate control group, I employed a case-cohort sampling design, through which I match the two closest non-entrepreneurial scientists to each entrepreneur, based on a number of observed demographic characteristics. As the goal was to estimate the effects of an entrepreneurial spell at different times, I used entrepreneurship as a state variable, as well as a treatment, to estimate the long-term effects.

My results for the effect on productivity are in line with the findings of Toole and Czarnitzki (2010) and show that entering academic entrepreneurship is related to a drop in productivity of around 25% as academics shift their focus away from scientific knowledge production. My findings further suggest that this effect persists even when returning to academia full time, but it is attenuated in the long run. Regarding collaboration, the findings suggest that scientists shift the set of co-authors towards new but fewer repeated collaborations. This result indicates that academic entrepreneurship may also affects how scientists collaborate and the value given to entrepreneurial scientists as co-authors. Further, this paper shows that these effects differed, depending on start-up size. Additional analyses did not find conclusive evidence that these effects can be fully explained by individual characteristics, such as seniority, or a shift in scientific topics, nor that academic entrepreneurs shift their attention towards more impactful work (Fini et al., 2021) or patenting (Azoulay, Liu, & Stuart, 2009).

Thus, by gaining a better understanding of the effects of such activities, this paper contributes to the literature on the effects of academic entrepreneurship on scientific knowledge production (Toole & Czarnitzki, 2010; Argyres & Liebeskind, 1998; Shibayama, Walsh, & Baba, 2012). These contributions pertain to evaluating what effects academic entrepreneurship has after returning to academia by differentiating between immediate and long-term effects. A further contribution to the literature is the investigation of effects on other aspects of knowledge production, such as collaboration (Rahmandad & Vakili, 2019; Jones, 2009; Teodoridis, 2018). This research further contributes to the economics of science literature by showing how incentives and individual decisions affect the rate and scope of academic research (Rosenberg, 1982; Sohn, 2020).

4.2 Theoretical Framework

In the linear model of innovation, basic research and the commercialization of technologies are conducted in different sectors of the economy and are governed by distinct sets of norms and institutions (Merton, 1973). However, the boundaries between these sectors are becoming increasingly blurred. Thus, firms are increasingly building on knowledge produced in universities (Marx & Fuegi, 2020) by collaborating with university researchers or accessing such human capital by hiring scientists (Cassiman, Veugelers, & Arts, 2018; Kaiser, Kongsted, Laursen, & Ejsing, 2018). Further, university researchers are increasingly encouraged to commercialize their findings (Powell & Owen-Smith, 1998).

However, these interactions have also been shown to affect the activities of university researchers, especially through different norms of disclosure and publication (Sauermann

& Stephan, 2013). While a key goal for academic scientists is to publish and disseminate their findings, private sector firms value secrecy and the protection of intellectual property (Merton, 1973; Dasgupta & David, 1994). Thus, a stream of literature has explicitly focussed on the role of intellectual property rights on the diffusion of scientific knowledge (e.g., Murray & Stern, 2007). Making use of the time lag between the publication and patenting of *ideas*, these studies show that once *ideas* are patented, citations to the scientific papers decline. These findings point towards a negative role of intellectual property rights and commercial interests on scientific knowledge production.

Beyond the effects on the cumulative production and dissemination of knowledge, commercialization and collaborations with industry also affect the output of individual scientists (Azoulay et al., 2009). In a study of biology and biotechnology scientists, Evans (2010) showed that academic scientists collaborating with industry directed their research efforts towards more novel experiments and away from testing theories. Further, Perkmann and Walsh (2009) demonstrated, that engaging with industry led to more exploratory learning by university scientists. These studies contend that collaborating with industrial partners may make scientists more aware of research they did not know about before (Evans, 2010) and may lead to high levels of partner interdependence that allow for exploratory learning (Perkmann & Walsh, 2009).

It is, however, important to distinguish between different forms of academic engagement. While the prior findings were related to the consequences of collaboration with industry, they may not fully translate to the context of academic entrepreneurship. The most important distinction between collaboration with industry and academic entrepreneurship is that the latter involves the direct participation of academics in the establishment of firms (Perkmann et al., 2013). Thus, they differ in terms of their antecedents. While academic entrepreneurship is mainly conducted with the objective of generating additional income by exploiting prior discoveries, there are wider sets of motives for collaborating with industrial partners (Perkmann et al., 2013; Jensen & Thursby, 2001). Aditionally, the consequences of academic entrepreneurship are also likely to differ from other forms of engagement and collaboration as it requires significantly more time and a greater allocation of resources (Stephan & Levin, 1996; Cohen et al., 2020), which then cannot be spent on research. Prior studies have investigated the positive and negative effects of academic entrepreneurship on the output of scientists, with contradictory results. The differences between these findings could be explained by differences in samples, fields, type of start-up, intensity of involvement and time, and how much time has passed since the entrepreneurial spell.

4.2.1 Productivity

Transitioning to academic entrepreneurship affects the productivity of scientists. Prior studies have pointed out that a main challenge academic entrepreneurs face is balancing their responsibilities in the firm with those at the university (e.g. Cohen et al., 2020; Sauermann & Stephan, 2013). Setting up a firm requires a high level of involvement from the scientist, and the allocation of substantial effort away from research and towards their venture (Stephan, 1996). Further, starting a company can shift the incentives of scientists away from publishing and towards the commercial exploitation of prior discoveries (Fini et al., 2021).

A number of studies have therefore investigated how the transition into academic entrepreneurship affects the productivity of scientists. In a study of scientists at the National Institutes of Health (NIH), Toole and Czarnitzki (2010) found that scientists leaving academia for entrepreneurship faced a significant drop in their productivity. They quantified these trade-offs and showed that academic entrepreneurs reduced their yearly number of publications by around 19% once starting or joining a firm (Toole & Czarnitzki, 2010). However, it is not clear what precisely drives this effect, as scientists who leave academia for entrepreneurship, also lose their incentives to publish (Fini et al., 2021). Thus, studies focussing on academic entrepreneurs maintaining their university employment have found either mixed or positive effects (e.g., Abramo, D'Angelo, Ferretti, & Parmentola, 2012; Fini et al., 2021). However, these findings are contested by a number of other studies. In a study of German scientists at the Max Planck Institute, Buenstorf (2009) found that researchers who are listed as founders of spin-offs had significantly fewer publications and citations after founding. Roche (2020) found that an academic's productivity dropped after founding a company and that this also had wider negative effects, particularly on their PhD students.

Highlighting the trade-offs and investments connected to entrepreneurship, I hypothesize that:

Hypothesis (H1a): *During an entrepreneurial spell, academics will orient their efforts away from research and therefore publish less.*

However, other studies have identified mechanisms through which academic entrepreneurship is positively associated with productivity. These authors have argued that academic entrepreneurship endows scientists with additional financial resources as well as larger networks outside of academia (e.g. Buenstorf, 2009; Bikard, Vakili, & Teodoridis, 2019). Further, it has been shown that academic entrepreneurship alters the search behavior of scientists towards more novel and impactful topics (Fini et al., 2021). Taken together, it can be argued that the contradictory effects identified by prior studies result from differences in their timing and duration of impact. Thus, allocating time away from research, can be argued to have an immediate effect on productivity. The other effects, such as a change in topics, networks, and potentially resources, however, can also be argued to affect scientists' trajectory once they return to academia full time (Evans, 2010; Fini et al., 2021; Bikard et al., 2019). I therefore argue that the effect of academic entrepreneurship on productivity will differ relative to the time that has passed since academic entrepreneurship. Thus, while the negative effects will be immediate and prevail in the short run, positive spillovers from an entrepreneurial spell will attenuate this effect in the long run.

Hypothesis (H1b): *Immediately after an entrepreneurial spell, the productivity of former academic entrepreneurs will be lower than the productivity level of their non-entrepreneurial peers.*

Hypothesis (H1c): *In the long run, the productivity of former academic entrepreneurs will converge with the productivity level of their non-entrepreneurial peers.*

4.2.2 Collaboration

Due to the increasing burden of knowledge and returns to teamwork, collaboration is becoming the dominant mode of knowledge production in science (Uzzi, 1996; Jones, 2009; Rahmandad & Vakili, 2019). Factors driving collaboration are oftentimes associated with an increasing complexity of scientific problems, making it impossible for sole researchers to solve them (Basalla, 1988; Jones, 2009).

The choice of collaborators, however, is made on the individual level. Scientists tend to prefer collaborators with whom they share common knowledge but who are not too similar as to prevent learning opportunities (McPherson, Smith-Lovin, & Cook, 2001; Dahlander & McFarland, 2013). The repetition of a collaboration, however, depends on its revealed quality and the value of the output, which can not be observed ex ante. Thus, more successful collaborations in terms of their value and quality of the output are more likely to be repeated (Dahlander & McFarland, 2013; Burt, 2002). Prior expertise and the level of specialization determine both, how beneficial it is for the individual scientist to collaborate and also the attractiveness of a scientist as a collaborator for others (Jones, 2008). I thus argue that academic entrepreneurship will have significant effects on a scientist's knowledge and skill accumulation and will subsequently affect collaboration patterns during and after the entrepreneurial spell.

Above, I argued that during an entrepreneurial spell, scientists will direct their efforts away from scientific publishing and will subsequently publish less. Following the same arguments, similar effects are expected regarding collaboration. Thus, as scientists allocate less time to scientific knowledge production, they might also try to reduce coordination costs and therefore rely to a larger extent on existing co-authorships. Another effect of academic entrepreneurship is that scientists shift their research towards more novel topics (Fini et al., 2021). However, as they lack knowledge and expertise on these novel areas, they turn to collaborating with experts in these new fields (Arts & Fleming, 2018). Taken together, it is expected that the reduction in overall investments in science will outweigh the search for new collaborators, leading to the hypothesis:

Hypothesis (H2a) *During an entrepreneurial spell, academics will have fewer repeated co-authorships than their non-entrepreneurial peers.*

An entrepreneurial spell is also likely to affect collaboration patterns in the long run. First, academic entrepreneurship leads academics to acquire different skills beyond pure research skills, differentiating them more from their non-entrepreneurial peers. Thus, in contrast to regular employees, entrepreneurs do not solely perform one specialized task but are required to take on multiple roles at the same time. These include making managerial decisions, negotiating with suppliers and customers, managing teams, and conducting specialized operational tasks (Lazear, 2005). It is therefore commonly argued that entrepreneurship allows individuals to acquire a particularly broad set of skills and expertise that are commonly associated with performing managerial tasks. By tracing the employment trajectories of workers, an increasing number of studies investigating the *treatment effect* of entrepreneurship have found that former entrepreneurs have a higher probability of joining an established firm in a managerial role (Manso, 2016; Merida & Rocha, 2021). This suggests that entrepreneurship leads to the accumulation of managerial skills to a greater extent than other types of employment.

Another set of skills that is commonly linked to entrepreneurship is the coordination of different stakeholders and the ability to pitch ideas to potential investors and customers (Lazear, 2005). These skills can be especially beneficial in identifying potential collaborators and coordinating tasks between highly specialized team members. For scientific knowledge production, these findings imply that academic entrepreneurship can in the short run harm co-author networks, but may in the long run endow the entrepreneur with skills that positively affect the recognition of opportunities (Shane, 2004) and the formation and efficacy of ties (Catalini, 2016). During an entrepreneurial spell, academics need to translate their knowledge to non-academic stakeholders, and coordinate with external stakeholders in order to achieve their commercial goals. These skills are beneficial for scientific knowledge production as the knowledge and skills acquired during an entrepreneurial spell differentiate scientists from their non-entrepreneurial peers, which in turn increases the probability of forming new co-authorships (Dahlander & McFarland, 2013).

However, spells of academic entrepreneurship can also decrease the value of scientists as collaborators because giving more attention to applied problems and commercialization may contradict the preferences and norms of academic scientists (Sauermann & Stephan, 2013), which can in turn lead to conflicts regarding research goals and disclosure of results. Furthermore, academic entrepreneurship has also been shown to direct scientists' research efforts towards new and unexplored topics. Fini et al. (2021) showed that academic entrepreneurs are more likely to explore novel fields. Evans (2010), found that engagement with industry induces scientists to shift their focus towards more novel and peripheral topics. However, exploration comes at a cost for these individuals, as they lack prior expertise, and learning costs and unfamiliarity have been shown to decrease productivity and the value of the subsequent output (Arts & Fleming, 2018; Myers, 2020). Scientists can overcome these negative effects through collaboration (Arts & Fleming, 2018). Further, exploration induced by academic entrepreneurship may also come at the expense of knowledge depth (Jones, 2009). Thus, while generalists might be useful to broker knowledge between highly specialized collaborators (Teodoridis, 2018; Melero & Palomeras, 2015), they may be less able to offer sufficient complementary knowledge, which is especially relevant for repeated collaborations (Dahlander & McFarland, 2013; Jones, 2008). Dahlander and McFarland (2013) pointed out, that the mechanisms leading to the formation of ties are different from those leading to repeat collaborations. They argued that the initiation of collaborations is mainly driven by an ex-ante consideration of matching traits, often favoring unfamiliarity. The persistence of such ties, however, is driven by a reflection on the value of the output (Dahlander & McFarland, 2013) and the revealed quality of the collaboration (Burt, 2002).

I therefore hypothesize that:

Hypothesis (H2b): *Immediately after an entrepreneurial spell, academics will have fewer repeated co-author relationships than their non-entrepreneurial peers.*

Hypothesis (H2c): *In the long run after an entrepreneurial spell, academics will have fewer repeated co-author relationships than their non-entrepreneurial peers.*

4.2.3 Role of Firm Size

A factor that can potentially affect the relationship between academic entrepreneurship, productivity, and collaboration is the size of the start-up, which can be considered both a choice (Folta, Delmar, & Melillo, 2012) and a measure of success, and has important consequences on the performance of the start-up (Almeida, Dokko, & Rosenkopf, 2003). This discussion only considers potential factors through which the size of the start-up can affect the productivity and collaboration patterns of scientists. There are two potential mechanisms through which the start-up size can affect scientists' productivity and collaboration patters: the allocation of time and the accumulation of skills and potential spillovers from the commercial activity onto the founders'.

The administrative burden increases with the number of employees. Thus, it can be argued that the required time allocated to and involvement in the start-up is less for those entrepreneurs without employees. However, employees also allow for a greater division of labor. This might imply that the academic can outsource coordination tasks and remain focussed on research. Thus, it is not clear whether the benefits of having employees outweigh the costs.

Considering post-entrepreneurial outcomes, however, it can be expected that entrepreneurs with employees will experience a larger treatment effect. One explanation for this pertains to the accumulation of managerial skills. However, the extent to which managerial skills are acquired likely depends on the size of the venture as well as the number of employees managed (Lazear, 2005). Thus, employing workers, requires the founder to allocate and coordinate tasks between employees. These skills can also be valuable for collaborative knowledge production in science, where the allocation of tasks and recombination of knowledge is crucial (Teodoridis, 2018).

Another way in which ventures with employees differ from those without is the extent to which they allow for learning. Almeida et al. (2003) showed that as start-up sizes increased opportunities for internal learning also increased. Thus, the main benefits identified in prior studies (e.g. Fini et al., 2021) increase with venture size. Additionally, larger ventures are also more likely to be more successful and provide the entrepreneur with access to larger networks and resources.

I therefore hypothesize that:

Hypothesis (H3): *After an entrepreneurial spell, entrepreneurs with employees will be less productive, than those without.*

Hypothesis (H4): *After an entrepreneurial spell, entrepreneurs with employees will have fewer repeated collaborations, than those without.*

4.3 Data and Empirical Strategy

4.3.1 Data and Sample

In order to evaluate how academic entrepreneurship affects the number of publications and collaboration patterns of academics, I constructed a unique dataset of Danish scientists by merging the Danish linked employer–employee data with publication data. The target population was university scientists. I defined universities based on the institutions register (INST) and a matched list of university tax numbers. To further differentiate researchers from other university employees, I made use of the education and occupation codes. Thus, I focused on those researchers with a PhD or master's degree who were classified as university teachers or researchers according to the Danish version of the International Standard Classification of Occupations. The final criterion included into the sample was a matched Scopus author profile. This match was conducted by Denmark Statistics (DST) based on names and affiliations for all Danish authors affiliated with a university and employed between 1999 and 2016. While information on employment spells were only available during this time period, the publication data contain yearly information on researchers' publication outputs from 1970 to 2018. I further limited the sample to researchers in science, technologym engineering and math (STEM) fields, as academic entrepreneurship is concentrated in these fields and is linked to the commercialization of discoveries, rather than pure consulting activities (Perkmann et al., 2013)

Following prior studies investigating the effects of entrepreneurship (e.g., Toole & Czarnitzki, 2010), I used a case-cohort sampling design to define the sample. Thus, for each of the 149 academics who started a company between 2004 and 2008, I matched them with the two most similar non-entrepreneurial scientists as a control. In order to do so, I conducted nearest neighbour matching based on *birth year, gender, field, first affiliation, and year of career start*. For each control scientist, I defined the entrepreneurial spell, as well as the pre and post period, analogously to the academic age of the matched entrepreneur. Thus, if an academic started a company at academic age 15 and ended at age 19, I compare her performance during the entrepreneurial spell with the performance of the control scientists at academic age 15 to 19. This resulted in a sample of 447 individual scientists, and 8,046 individual-year observations, covering the years 1999 to 2016.

4.3.2 Variables

Dependent Variables

To evaluate the impact of academic entrepreneurship on the productivity of scientists and their collaboration patterns, I defined a series of dependent variables. The first one, publication productivity (*NbPubYear*), was defined as the number of publications a scientist i published in year t.

The second outcome measure aimed to capture changes in the collaboration patterns of entrepreneurs. Thus, for each co-author in a given year, I evaluated whether that was their first year of co-authorship, or if they had collaborated before. I therefore constructed the variable repeated co-authorships (*RepeatCoAuth*) to measure the number of unique co-authors with whom the scientist had published before.. As the value of co-author ties was only revealed ex-post, this variable contains information about the productivity of co-authorships.

Academic Entrepreneurs

I defined academic entrepreneurship as a commercial activity involving the formal establishment of a firm while retaining their employment at a university. Thus, I made use of the Danish linked employer–employee database, which specifies multiple types of employment per year per individual and defined university researchers who were also considered as *self-employed* or an *employer*. I focused on those who entered entrepreneurship during a 5-year period from 2004 to 2008, which falls in the middle of the sample. This allowed me to observe the pre- and post-entrepreneurial period.

To estimate the effects of academic entrepreneurship in the short and long run, it is crucial first clearly define academic entrepreneurship. In prior studies, academic entrepreneurship was mainly considered a one-time switch and therefore operationalized as a state variable, i.e., a dummy variable switching from a value of 0 to 1 in the year a scientist enters entrepreneurship (Toole & Czarnitzki, 2010; Fini et al., 2021). Thus, I followed this approach to define the variable *SelfEmp* in order to estimate the effect on productivity and collaboration during entrepreneurial spells.

To further estimate the long-term effects, I followed more recent work conceptualizing entrepreneurship as a treatment (Manso, 2016; Merida & Rocha, 2021; Sorenson, Dahl, Canales, & Burton, 2021). I therefore took advantage of the fact that academic entrepreneurship can also be a temporary activity and that academics may return to full-time university employment afterwards. I therefore defined a dummy variable *EntrDum*, for academics who had an entrepreneurial spell between 2004 and 2008 to evaluate their outcomes in two post treatment periods, i.e., 1 to 4 years and 5 to 9 years after the entrepreneurial spell.

Control Variables

I also included a set of control variables, to take into account other factors that could affect the productivity of academics. *Age* and *Age sq.* accounted for life cycle effect of productivity. I also included a control variable for specialization, which has commonly been associated with productivity and collaboration (e.g. Teodoridis, 2018) specialization

(*Spec*). In line with previous research (Melero & Palomeras, 2015), I define it in terms of the Hirschman-Herfindahl Index (HHI):

$$HHI = \sum_{n=1}^{333} (Share_a)^2, \tag{4.1}$$

where a refers to the field classification assigned to journals, as defined by the ASJC codes. The HHI ranges from 0 to 10,000, with higher values indicating higher levels of specialization. This variable is defined based on the publications published from year $t - 5$ to $t - 1$. Further, I included the number of new ASJC codes per year, (*NewASJC*). This is particularly relevant in the specifications for repeated co-authorships, as a shift in co-authorships can also be driven by exploring new fields (Arts & Fleming, 2018).

Additionally, I included the number of previously won grants from the Danish research council (*NbGrants*). As these grants are highly competitive, they provide an indication of the overall quality of a scientist's work. To control for pre-treatment levels of productivity and repeated collaborations, I also included the average number of publications per year in the years prior to the entrepreneurial spell (*AvgPubPreAe*), as well as the average number of repeated collaborations per year (*AvgRepeatCollabPreAe*). Further, the specifications about repeated co-authorships, also included the number of publications (*NbPubYear*) and number of unique co-authors (*NbCoauth*) per year, to ensure that results are not influenced by the extent of output or number of collaborators in a year.

4.3.3 Empirical Strategy

The goal of this paper is to evaluate how academic entrepreneurship shapes the productivity and collaboration patterns of the involved academics, both in the short and in the long run. For this purpose, I estimated OLS regressions on the productivity and collaboration patterns of academics at three different time windows.

The first window was the time spent in academic entrepreneurship. For this purpose, I use the full length of the panel (1999–2016), and included a dummy variable, taking the value 1 for years in which an academic was classified as an entrepreneur. Next, I considered the treatment effect of academic entrepreneurship and estimated the effects in the first 4 years and 5 to 9 years after leaving academic entrepreneurship and returning to academia full time. All models included *university* and *year* fixed effects. I further followed Sorenson et al. (2021) and Burton, Dahl, and Sorenson (2018) and included triplet fixed effects. As the matching was conducted based on a number of observable demographic characteristics, the triplet fixed effects adjust for a particular combination of attributes to have flexible independent and joint effects on the dependent variable. Further, they absorb common time-invariant unobserved characteristics of these triplets, such as effects specific to fields, cohorts, and early career imprinting.

To further test the robustness of my results, I followed the approach proposed by Toole and Czarnitzki (2010) to conduct a conditional difference-in-differences analysis, based on the matched sample. Further, I ran a number of robustness checks, including quality adjusted publication count and patenting output. I further explored numerous potential moderators, such as seniority and exploration.

Identification Concerns

A main concern of this analysis is that it is likely to omit factors that are related to both, becoming an academic entrepreneur as well as to subsequent performance and collaboration patterns. While the employed empirical strategy should ensure that entrepreneurs are as similar as possible to the control group and are matched based on pre-entrepreneurship characteristics, it cannot fully exclude that there are factors that affect both the decision to become an entrepreneur and productivity and collaboration patterns. I therefore discuss what potential threats exist, how the employed strategy alleviates such concerns, and how the remaining concerns can be addressed.

First, the matching approach alleviates concerns that pre-entrepreneurship characteristics, such as differences in productivity levels, affect post-entrepreneurship outcomes (Zucker, Darby, & Armstrong, 1998). A second factor relates to the formation of entrepreneurial preferences. Workplace peers and early exposure to entrepreneurship shape entrepreneurial preferences (Stuart & Ding, 2006; Bercovitz & Feldman, 2008; Nanda & Sørensen, 2010). By matching based on the first affiliation, the employed approach should control for this factor. Further, while entrepreneurial preferences may be shaped along the career, the precise timing will depend on idiosyncratic shocks and scientific discoveries.

A third concern regards the nature of research and a taste for commercialization. Assuming that these are time-invariant traits, the included triplet fixed effects should account for this. A final concern might be related to the latent commercializability of research. However, this is likely to be constant over time, so the triplet fixed effects should account for this as well.

There are numerous predictors for entrepreneurial entry, such as exposure to entrepreneurial colleagues and co-authors (Tartari, Perkmann, & Salter, 2014). These, however, are also highly related to the outcome measures of interest, as there are also peer effects regarding the output (Azoulay & Zivin, 2005; Agrawal, McHale, & Oettl, 2017), and collaborations are often formed locally (Dahlander & McFarland, 2013). Another potential instrument is entrepreneurial parents. This has shown to be related to entrepreneurial entry (Vladasel, Lindquist, Sol, & Van Praag, 2020), and is unlikely to be related to subsequent academic outcomes. Unfortunately, the computation of this variable is not feasible for the entire sample, as self-employement spells were only observable after 1980. Further, due to the average age of academics in the sample, a large share of parents had already entered retirement. For the sub-sample for whom computation was possible, parental entrepreneurship, showed only weak predictive power.

Thus, the identification of the effects of academic entrepreneurship relies on the assumption that entrepreneurial preferences are formed early and are time invariant and that the formation of a firm and its precise timing depends on serendipitous discoveries. Finally, the periods for the treatment effect estimations were defined relative to the end year of the entrepreneurial spell. This adds additional robustness as it is difficult to determine other factors explaining changes in the outcomes for entrepreneurs that do not affect their matched peers.

4.4 Results

4.4.1 Descriptive Statistics

The sample consisted of 149 academics who started a company between 2004 and 2008. The average spell length was 3.60 years with a standard deviation of 3.24 years, and 77% of spells lasted 5 years or less. Table 4.1 provides the summary statistics of the sample. Table 4.2 further presents the correlation matrix. While this table reveals some high correlations between independent variables included in the same model, this is unlikely to be problematic as these correlations are only between control variables and not between any control and independent variables of interest (*SelfEmp, EntrDum*) (Wooldridge, 2002). Further, the variance inflation factor was less than 5 for all controls[1] and never exceeded 2 for the independent variables of interest.

— Insert Table 4.1 and Table 4.2 about here —

Table 4.3 shows pre-treatment differences between academic entrepreneurs and the matched control group. It reveals that the groups were balanced along most dimensions. However, the groups differed regarding their level of specialization, revealing that entrepreneurs were on average more specialized. The balance of the sample is further shown in Figures 1 and 2, which provide a descriptive preview of the expected effects.

— Insert Table 4.3 about here —

Figure 1 illustrates that entrepreneurs did not differ from their matched peers in terms of yearly publications prior the entrepreneurial spell, but their output dropped in the 2 years immediately after the spell. However this was attenuated as time passed. Figure 2 shows the difference in the number of repeated co-authorships. Again, no pre-entrepreneurship differences were found, differences arose immediately after entrepreneurship and persisted. However, as these are merely raw differences in means, the regression results are discussed below.

[1]except for *Age* and *Age sq.*

— Insert Figure 4.1 and Figure 4.2 about here —

4.4.2 Econometric Results

Table 4.4, presents the estimated effects of academic entrepreneurship on productivity during different periods. Model 1 presents the coefficients for the state of being an entrepreneur, and Models 2 and 3 show the short-term (1–4 years) and long-term (5–9 years) effects after the entrepreneurial spell. In contrast to

— Insert Table 4.4 about here —

Fini et al. (2021), I found that academic entrepreneurs published significantly less during their entrepreneurial spell. More specifically, entrepreneurs published 0.587 papers fewer per year than their matched peers. Considering that the average number of yearly publications in the included sample was 2.246, this can be interpreted as a 25% drop in yearly publication output. Model 2 further shows that this decrease persisted in the short run. In this period, entrepreneurs published on average 21% fewer papers per year than their matched peers. However, these negative effects were attenuated in the long run. These findings are further supported by Figure 1, which shows the raw mean differences between entrepreneurs and their matched controls in the years before and after the entrepreneurial spell. Overall, this is in line with propositions that academic entrepreneurship shifts the attention of scientists away from research (Stephan & Levin, 1996). However, these findnings also suggest that academic entrepreneurship does not harm the productivity of scientists in the long run (Toole & Czarnitzki, 2010); the negative effect is attenuated over time, allowing scientists to catch up to the productivity levels of their non-entrepreneurial peers. However, in contrast to Fini et al. (2021), I did not find evidence that these productivity levels exceeded those of their peers, and therefore not confirm any positive spillovers to productivity in the investigated period.

Having shown that academic entrepreneurship has a negative effect on productivity in the short term, but no effects in the long run, I now present the results regarding the collaboration patterns. As discussed in Section 2, pure team size may cover important heterogeneity regarding the underlying dynamics of formation and persistence of co-author ties. I argued above that an entrepreneurial spell is likely to change the scientists' expertise, which is relevant for collaboration. Thus, the value of the acquired expertise can be revealed by repeated co-authorships. I therefore explicitly tested this by exploring the yearly number of repeated co-author ties.

Thus, the value of co-author relationships will only be revealed ex-post. If skills acquired through entrepreneurship are valuable for collaborative knowledge production, more co-authorships are expected to be repeated. Models 4–6 in Table 4.4 present the results for repeated co-authorships. The results of Model 4 show that during entrepreneurial spells, there was no difference between academic entrepreneurs and their non-entrepreneurial peers. Thus, Hypothesis 2a is rejected. Directly after an entrepreneurial spell, entrepreneurs had 10% fewer repeated co-authorships. These effects become more pronounced and statistically significant in the long run. To put this finding into context, all authors in the sample collaborated on average with 2.8 author, with whom they had collaborated before. The coefficient in Column 6 suggests that for prior entrepreneurs, the number of repeated co-authorships was around 0.374, or 13% less. To exclude the possibility that this was driven by an overall reduction in the number of co-authors per year, I also controlled for the total number of co-authors per year. These findings provide indicative evidence that entrepreneurial expertise might deter repeated collaboration. Thus, Hypotheses 2b and 2c are supported.

— Insert Table 4.5 about here —

To provide more nuance to these results, I also tested whether this shift in co-authorships could be connected to changes in team size or the over all number of collaborators (Table 4.5) (Teodoridis, 2018). Models 1–3 present the effects of academic entrepreneurship on the average team size per year, which were not statistically significant. The same results were found for the first years after an entrepreneurial spell (Model 2). However, in the long run, academic entrepreneurs seemed to work in significantly smaller teams ($p < 0.10$), with an average of 1.8 fewer co-authors per paper. However, the results for the extensive margin of collaboration, i.e., the number of unique collaborators per year, were stronger for models 4–6. Model 4 shows that during an entrepreneurial spell, academics reduced the number of collaborators by approximately 15% compared to their non-entrepreneurial peers. This is also in line with the hypothesis that academic entrepreneurship leads scientists to shift their attention away from scientific knowledge production, which results in managing fewer co-author relationships. However, in contrast to the total output, this effect was not attenuated. Thus, in the first 4 years after an entrepreneurial spell, have on average 27% less co-authors, and in the subsequent period (5–9 years), collaborated with 25% less co-authors per year, than their non-entrepreneurial peers.

4.4.3 Results for role of firm size

Academic entrepreneurship also had an effect on productivity and collaboration patterns depending on the size of the venture. To test whether different types of entrepreneurs are affected differently, I constructed a categorical variable with 0 assigned to academics who were never entrepreneurs, 1 to entrepreneurs without employees (*SelEmpNoEmpl* and *EntrDumNoEmpl*), and 2 to entrepreneurs with employees (*SelEmpWithEmpl* and *EntrDumWithEmpl*). Table 4.6 reveals that there was no difference in the effect on productivity during the entrepreneurial spell, but both groups of entrepreneurs had a similar and statistically significant drop in the number of publications per year. After the entrepreneurial spell, the downward trend continued for those entrepreneurs without employees, who showed an average of 0.6 fewer publications, whereas those with employees did not have any significant decrease in the short term. However, the difference between these two groups was not statistically significant, as revealed by a Wald test ($p = 0.229$). In line with the main effect, neither of the groups showed any significant difference in publication output, in the long run after an entrepreneurial spell. Thus, while the results do not confirm Hypothesis 3, they do indicate that that entrepreneurs with employees were able to recover their output more quickly.

— Insert Table 4.6 about here —

The effects on repeated co-authorships show a similar pattern (Table 4.6, Model 4–6). Model 4 shows that the decrease in productivity did not differ between entrepreneurs with employees and those without. In the first years after an entrepreneurial spell, however, entrepreneurs differ, and entrepreneurs with employees have significantly fewer repeated collaborations than both non-entrepreneurs and entrepreneurs without employees ($p = 0.023$). In the long run, the difference between the two groups of entrepreneurs disappeared. While both groups of entrepreneurs faced a quantitative decrease compared to non-entrepreneurs, this difference was only significant for those entrepreneurs without employees, but it was economically more pronounced for those with employees. This lends partial support for Hypothesis 4. Taken together, these findings suggest that the a larger entrepreneurial venture might allow an academic to benefit from a greater division of labor, which leading to their output to suffer less shortly after an entrepreneurial spell. In the long run, however, there seems to be a larger negative effect on repeated collaborations for entrepreneurs with employees, lending support to the hypothesis of academic entrepreneurs accumulating skills and preferences that could be harmful to collaborative knowledge production in science.

4.4.4 Robustness Checks

As an additional robustness check, I conducted a conditional difference-in-differences analysis. For each of the outcomes, I applied a within comparison for each individual for the time during an entrepreneurial spell and for the pre and post periods. To do so, I closely followed the procedure proposed by Toole and Czarnitzki (2010) using the following model:

$$y_{it} = \beta_1 * SelfEmp_{it} + \beta_2 * SelfEmpCont_{it} + \beta_3 * X_{it} + \gamma_i + \theta_t + \varepsilon_{it}, \tag{4.2}$$

where *SelfEmp* is a dummy variable taking the value 1 for the years during an entrepreneurial spell. *SelfEmpContr* is a dummy variable specified for the control scientists only, which takes the value 1, for the years during an entrepreneurial spell of the matched scientist. To estimate the effects on post-entrepreneurship outcomes, I defined dummies taking the value 1 in the year an academic leaves entrepreneurship, which were labelled *PriorEntr* and *PriorEntrContr*. These estimations exclude years during entrepreneurship and thus provide a before and after comparison. The models further contain a vector of time-variant control variables X, which differ depending on the outcome variable and correspond to those included in the main models. I further include individual (γ) and year (θ) fixed effects.

— Insert Table 4.7 about here —

Table 4.7 presents the results for the productivity regressions in Models 1 and 2. Academic entrepreneurs had significantly lower yearly outputs during and their entrepreneurial spell, while this is not the case the matched control scientists. Further Wald tests revealed a significant difference between the groups during an entrepreneurial spell ($p = 0.02$) but not after ($p = 0.17$). As the post period for regressions included the first 9 years after an entrepreneurial spell, these findings largely corroborate the prior findings. The results for repeated co-authorships (Models 3 and 4) further confirm the prior findings, showing no significant difference between entrepreneurs and non-entrepreneurs during a spell ($p = 0.35$) and a weakly significant differences afterwards ($p = 0.098$). As shown above, there was no significant effect on *TeamSize* but increasingly strong effects on *NbCoauth*.

The results regarding the collaboration measures were more robust. For each comparison, significantly negative effects were shown for academic entrepreneurs, but no significant effects were found for the control dummy.

As the dependent variables represent count data, I also re-estimated the effects, using negative binomial and Poisson models. The results for the publication count remained largely robust. The results regarding the repeated co-authorships are corroborated in terms of sign, but not in terms of significance.

4.4.5 Alternative Explanations

Quality Adjusted Output The results of the main analysis imply that scientists shift their attention away from research and towards entrepreneurial activities and that this harms the quantity of their output. While this is in line with some prior findings (e.g.

Toole & Czarnitzki, 2010; Buenstorf, 2009), the question remains as to whether academic entrepreneurship also harms the quality of the publication output. In order to test this, I weighted the number of publications per year by the number of citations received within a 3- and 5-year citation window.

— Insert Table 4.8 about here —

The results presented in Table 4.8 provide mixed evidence. While the coefficients suggest the quality of the adjusted output decreased during an entrepreneurial spell (Models 1 and 4), these effects were not significant. Further, the results show that after an entrepreneurial spell, academic entrepreneurs increased the quality of their output, and this difference compared to non-entrepreneurial peers increased as time passed. In these models a significant difference at the 5% level was only found for the 5-year citation window. This suggests that while scientists might face a drop in productivity in the short run, they shift their research focus towards more impactful research in the long-run. This finding is in line with that of Fini et al. (2021), who provided a detailed discussion about the potential mechanisms. However, this finding should also be interpreted with caution as it only applies to a small sub-sample of publications for which the full 5-year citation window could be observed (the last observed publication year was 2012). Given that the long term is defined as 5 to 9 years after an entrepreneurial spell, it only captures those entrepreneurs who ended their spell in or before 2007.

Exploration Prior studies have established that academic entrepreneurship shifts the attention of scientists towards novel research topics and affects their research impact through this mechanism. However, the exploration of new fields is also associated with a loss of human capital (Arts & Fleming, 2018). Thus, in order to be able to make a meaningful contribution to the new field, scientists need to invest in acquiring skills and knowledge in that field (Arts & Fleming, 2018; Jones, 2009). The effects of academic entrepreneurship on repeated collaborations could therefore be driven by exploration. While the above models included the number of new scientific fields as a control, I also explicitly tested, whether academic entrepreneurs who explored more, also have fewer repeated co-authorships.

— Insert Table 4.9 about here —

In order to test whether exploration moderates the effect of academic entrepreneurship, I interacted the the entrepreneurship dummies with the number of newly used ASJC codes (*NbNewASJC*). The results are presented in Table 4.9. Models 4–6 present the results for the interaction term with the number of newly used ASJC codes. As expected, the number of new ASJC codes was negatively associated with the number of repeated co-authorships. The interaction term can thus be used to determine whether entrepreneurship affects those who diversify their expertise differently from those who do not. The results show that in the long run, the interaction effect was negative and significant. This means that greater exploration among entrepreneurial academics resulted in a more negative effect on repeated co-authorship. This suggests that exploration induced by academic entrepreneurship, may in fact lead to a loss of expertise and therefore harm collaborative knowledge production in science. There is however no indication of a significant moderation effect of exploration on the yearly number of publications (Models 1–3).

Seniority The final potential moderator could be the seniority of scientists. Research is a process of skill and knowledge accumulation and therefore partially a routine activity. Thus, the older scientists are, the more easily they will be able to rely on established routines and thus better be able to compensate for time allocated to entrepreneurship.

— Insert Table 4.10 about here —

Table 4.10 presents the results for seniority. This variable is measured as a categorical variable taking the value 0 for non-entrepreneurs, 1 for entrepreneurs starting a company at or below the academic age of 10 years (*SelfEmpYoung, EntrDumYoung*), and 2 for those staring a company at an academic age older than 10 years (*SelfEmpOld, EntrDumOld*). Model 1 shows that during an entrepreneurial spell, younger academics were especially negatively affected. This difference, however, was not significant ($p = 0.826$). Model 2 does not reveal any difference between younger and older entrepreneurs either economically or statistically ($p = 0.840$). Model 3 shows that neither group was affected in the long run. A similar pattern was observed for repeated co-authorships (Table 4.10). Models 4 and 5 show that the effects were particularly negative for older academics, but this result was not significantly different from more junior academics ($p > 0.40$). However, Model 6 shows that in the long run, older academics faced the biggest shift in co-author ties, and the difference compared to younger academics became significant at the 10% level ($p = 0.094$). However, this does not provide conclusive evidence that the results can be explained by seniority.

Length of Entrepreneurial Spell To test whether the main effects differ depending on the length of the entrepreneurial spell, I divided the entrepreneurs into those who remained self-employed for only 1 year and those whose spell exceeded 1 year. The results suggest that the effects on productivity were mainly driven by an entrepreneurial spell lasting more than 1 year. No difference was found between the groups regarding the effects of the length of entrepreneurial spell on collaboration. The results are reported in Table 4.11.

— Insert Table 4.11 about here —

Shift from Publishing to Patenting An alternative explanation for why entrepreneurial scientists experience a drop in their output might be that they shift their attention to patenting. Thus, I used the number of patent applications ($NbPat$) as well as the instance of patenting ($PatDum$) in year t as the dependent variable and found that during an entrepreneurial spell, scientist also applied for fewer patents than their non-entrepreneurial peers. After the entrepreneurial spell, this difference prevailed, although it was and while less pronounced and statistically not significant. The results are reported in Table 4.12.

— Insert Table 4.12 about here —

4.5 Discussion and Conclusion

The goal of this paper was to evaluate the effects of academic entrepreneurship on the productivity and collaboration patterns of scientists. In so doing, this research acknowledges the often temporary nature of academic entrepreneurship and takes into account different types of academic entrepreneurship, and divides the group of entrepreneurs into self-employed and those generating employment. To hypothesize about the long-term impact of academic entrepreneurship, I drew on two streams of literature. First, the general literature on university–industry collaborations argues for a mainly negative effect of industry involvement on academic knowledge production. The more recent literature on entrepreneurship as a temporary spell of skill development, argues that academics can gain valuable skills through entrepreneurship, which may help to attenuate the negative effects on knowledge production in science.

I evaluated this on a sample of Danish academics during the period from 1999 to 2016 using a case-cohort design. My results for the effect on productivity are in line with the findings of Toole and Czarnitzki (2010) and show that entering academic entrepreneurship is related to a drop in productivity as academics shift their focus away from scientific knowledge production. My findings further suggest that this effect persists even when returning to academia full time, but this is attenuated in the long run. Regarding collaboration, my findings suggest that scientists shift of co-authors towards new but fewer repeated collaborations. This indicates that academic entrepreneurship may decrease the value of a scientist as a collaborator as exploration induced by entrepreneurship may lead to shallower levels of expertise, and an increased attention to commercialization may conflict with the publication objectives of the co-authors. The results further show that the effects on output and repeated co-authorships differed depending on whether the entrepreneur had employees or not. Employing workers can allow for a greater division of labor and therefore result in scientists' output to declining less after an entrepreneurial spell. However, my results suggest that academic entrepreneurs with employees had fewer repeated co-authorships in the long run. This lends support to the hypothesis that an entrepreneurial spell leads to the accumulation of skills and experiences that are not fully transferrable to knowledge production in academia and might even harm an academics' career. Further, this paper shows that these effects differed, depending on start-up size. Additional analyses did not find conclusive evidence that these effects can be fully explained by individual characteristics, such as seniority, or a shift in scientific topics, nor that academic entrepreneurs shift their attention towards more impactful work or patenting.

While this paper is not the first to evaluate the effects of academic entrepreneurship on scientific knowledge production, it extends this stream of literature by differentiating between academic entrepreneurship as a state and as a treatment. It further considers outcomes beyond output and impact, by looking at another important factor of knowledge production, which is collaboration. Overall it suggests that academic entrepreneurship can harm the rate of academic knowledge production in the short run and may have negative effects on the long-term collaboration patterns of scientists. This is especially important to consider against the background of the increasing importance of teams. This has important implications for science policy, as encouraging academics to commercialize their research may have negative consequences for academic knowledge production.

However, this paper is not free of limitations, which may reduce the generalizability of the findings. The first limitation is that I was not able to observe the actual time allocated to the entrepreneurial activity or publishing, which would represent a direct mechanism explaining the decline in productivity. Further, I am unable to differentiate whether are the effects on repeated co-authorships and a decline in unique co-authors is driven by the co-author or the entrepreneurs themselves.

Further, there is some concern regarding how these results can be compared to other contexts, like NIH scientists, faculty at Imperial College London, or scientists at the Max Planck institutes. In contrast to these prior findings, the results of this paper are not limited to an elite sample but rather the general population of scientists. While this might be appealing, it also introduces noise. Thus, there might be great heterogeneity in the type of of ventures, and in the extent to which they are actually relate to the commercialization of scientific discoveries.

Further, the current sample was limited to a rather short time frame considering the length of an academic career. This may obscure long-term effects, which, and may lead to the exclusion of successful entrepreneurs from the sample. I was further, also not able to observe the effects on other relevant outcomes, such as promotions and mobility. Finally, omitted variables affecting entrepreneurial entry, productivity, and collaboration remain a concern.

However, these limitations also represent promising opportunities for future research, especially regarding the spill-overs from academic entrepreneurship on scientific research. It would also be highly relevant to dedicate more research towards what scientists are able to benefit from academic entrepreneurship and what scientists are potentially harmed. This is especially relevant against the continued efforts of universities and policy makers encouraging scientists to commercialize their discoveries.

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Tables

Table 4.1: Descriptive statistics

	Count	Mean	S.D.
NbPubYear	8,046	1.806	3.506
TeamSize	8,046	2.758	10.048
NbCoauth	8,046	2.605	6.218
NbNewCoauth	8,046	1.253	3.148
NbRepeatCoauth	8,046	1.352	3.629
SelfEmp	8,046	0.070	0.255
EntrDum	8,046	0.333	0.471
AvgRepeatCoauthPreAe	8,046	0.448	1.066
AvgTeamSizePreAe	8,046	1.149	1.318
AvgNbCoauthPreAe	8,046	.889	1.848
NbGrants	8,046	0.433	1.085
Age	8,046	49.104	15.599
Female	8,046	0.215	0.411
Spec	8,046	1877.211	2267.539
NewASJC	8,046	0.658	1.447
AvgPubPreAe	8,046	1.002	1.824
N	8,046		

Table 4.2: Correlation table

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11	(12)	(13)	(14)	(15)
SelfEmp	1.00														
EntrDum	0.39	1.00													
NbPubYear	-0.06	-0.03	1.00												
NbRepeatCoauth	-0.04	-0.04	0.77	1.00											
TeamSize	-0.02	-0.03	0.20	0.22	1.00										
NbCoauth	-0.05	-0.03	0.78	0.93	0.26	1.00									
AvgPubPreAe	0.03	0.01	0.61	0.53	0.11	0.51	1.00								
NbGrants	-0.01	-0.05	0.24	0.19	0.07	0.18	0.46	1.00							
Spec	0.07	0.04	-0.05	-0.06	-0.01	-0.05	-0.05	-0.06	1.00						
NewASJC	-0.06	-0.02	0.41	0.26	0.16	0.34	0.08	0.03	0.01	1.00					
Female	0.00	0.00	-0.11	-0.09	-0.02	-0.08	-0.19	-0.17	-0.02	-0.01	1.00				
Age	0.12	-0.00	0.09	0.10	0.04	0.09	0.38	0.28	0.17	-0.07	-0.29	1.00			
AvgRepeatCoauthPreAe	0.04	0.03	0.57	0.64	0.12	0.61	0.87	0.34	-0.05	0.08	-0.16	0.29	1.00		
AvgTeamSizePreAe	0.04	0.01	0.38	0.37	0.15	0.36	0.76	0.39	0.00	0.05	-0.24	0.55	0.70	1.00	
AvgNbCoauthPreAe	0.04	0.03	0.57	0.64	0.13	0.63	0.87	0.34	-0.05	0.09	-0.17	0.32	0.99	0.74	1.00

Table 4.3: T-Tests pre-entrepreneurship characteristics

	Mean	S.D.	Mean	S.D.	Diff.	T Stat
NbPubYear	1.54	3.09	1.51	3.10	-0.03	(-0.26)
NbRepeatCoauth	1.04	2.53	0.94	2.67	-0.10	(-1.03)
TeamSize	1.96	3.21	1.99	2.88	0.02	(0.19)
NbCoauth	2.00	4.63	1.84	4.51	-0.16	(-0.95)
NbGrants	0.28	0.77	0.32	0.80	0.04	(1.40)
Spec	1726.90	2448.13	1526.99	2055.21	-199.91*	(-2.34)
NewASJC	0.51	1.17	0.53	1.29	0.02	(0.56)
Female	0.23	0.42	0.23	0.42	0.00	(0.00)
Age	43.79	15.63	43.74	14.45	-0.05	(-0.09)
Observations	1115		2230		3345	

Table 4.4: Regression results for publication count and repeated co-authorships

	(1) NbPubYear	(2) NbPubYear	(3) NbPubYear	(4) NbRepeatCoauth	(5) NbRepeatCoauth	(6) NbRepeatCoauth
SelfEmp	-0.587*			-0.00133		
	(0.238)			(0.0740)		
EntrDum		-0.478*	0.295		-0.187*	-0.374*
		(0.243)	(0.376)		(0.0789)	(0.150)
AvgPubPreAe	1.412***	1.330***	1.651***			
	(0.179)	(0.267)	(0.402)			
AvgRepeatCoauthPreAe				0.374***	0.540***	0.512**
				(0.0626)	(0.139)	(0.173)
NbGrants	-0.0369	0.0745	0.187	0.00865	0.0400	0.129
	(0.108)	(0.110)	(0.223)	(0.0402)	(0.0584)	(0.0823)
Spec	-0.0000452*	-0.0000827*	-0.000147**	0.00000727	0.00000785	0.0000174
	(0.0000195)	(0.0000323)	(0.0000550)	(0.00000668)	(0.0000131)	(0.0000299)
Age	0.540***	0.681***	1.030***	-0.00537	0.0141	0.0997
	(0.0685)	(0.115)	(0.190)	(0.0218)	(0.0478)	(0.0866)
Age sq.	-0.00514***	-0.00621***	-0.00949***	-0.000125	-0.000374	-0.00135
	(0.000675)	(0.00126)	(0.00203)	(0.000192)	(0.000453)	(0.000797)
NbCoauth				0.457***	0.414***	0.419***
				(0.0195)	(0.0245)	(0.0225)
NbPubYear				0.147***	0.176***	0.239***
				(0.0216)	(0.0399)	(0.0351)
NewASJC				-0.183***	-0.142**	-0.209***
				(0.0245)	(0.0506)	(0.0481)
University F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Triplet F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
_cons	-13.22***	-16.93***	-25.38***	0.251	-0.494	-1.428
	(1.931)	(3.165)	(5.344)	(0.599)	(1.374)	(2.725)
N	5456	1356	1209	5456	1356	1209
adj. R^2	0.555	0.551	0.530	0.883	0.883	0.893

Clustered standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4.5: Regression results average team size and number of unique co-authors

	(1) TeamSize	(2) TeamSize	(3) TeamSize	(4) NbCoauth	(5) NbCoauth	(6) NbCoauth
SelfEmp	-0.350			-0.519*		
	(0.243)			(0.233)		
EntrDum		-0.322	-1.836		-0.892**	-1.331**
		(0.295)	(1.093)		(0.278)	(0.475)
AvgTeamSizePreAe	1.233***	0.543**	0.679			
	(0.185)	(0.165)	(0.660)			
AvgNbCoauthPreAe				1.212***	1.377***	1.936***
				(0.221)	(0.206)	(0.366)
NbPubYear	0.379***	0.341***	0.411**	1.118***	1.095***	1.259***
	(0.0777)	(0.0751)	(0.124)	(0.0716)	(0.0872)	(0.0837)
NbGrants	-0.312***	-0.0711	-0.626	-0.292	-0.252	-0.505
	(0.0910)	(0.0910)	(0.333)	(0.152)	(0.158)	(0.323)
Spec	0.0000108	0.0000196	-0.000285	-0.00000600	0.00000153	-0.000160*
	(0.0000272)	(0.0000421)	(0.000194)	(0.0000211)	(0.0000372)	(0.0000804)
Age	0.317**	-0.00229	-0.118	0.000530	0.153	-0.0701
	(0.111)	(0.125)	(0.776)	(0.0978)	(0.141)	(0.283)
Age sq.	-0.00372***	0.000700	-0.000335	-0.00104	-0.00251	-0.00186
	(0.000997)	(0.00122)	(0.00705)	(0.000827)	(0.00136)	(0.00245)
University F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Triplet F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Intersect	-7.419*	0.0528	13.30	1.283	-1.397	12.07
	(3.071)	(3.430)	(21.96)	(2.793)	(3.842)	(8.899)
N	5177	1356	1209	5177	1356	1209
adj. R^2	0.132	0.303	0.069	0.733	0.781	0.780

Clustered standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4.6: Regression results for effects of firm size

	(1) NbPubYear	(2) NbPubYear	(3) NbPubYear	(4) NbRepeatCoauth	(5) NbRepeatCoauth	(6) NbRepeatCoauth
SelfEmpNoEmpl	-0.586*			0.0135		
	(0.296)			(0.0710)		
SelfEmpWithEmpl	-0.590*			-0.0548		
	(0.273)			(0.167)		
EntrDumNoEmp		-0.585*	0.284		-0.0895	-0.327*
		(0.271)	(0.403)		(0.0838)	(0.152)
EntrDumWithEmp		0.180	0.367		-0.791***	-0.675
		(0.561)	(1.112)		(0.223)	(0.549)
AvgPubPreAe	1.412***	1.322***	1.651***			
	(0.179)	(0.267)	(0.402)			
AvgRepeatCoauthPreAe				0.374***	0.553***	0.515**
				(0.0626)	(0.138)	(0.174)
NbGrants	-0.0369	0.0748	0.185	0.00848	0.0392	0.136
	(0.108)	(0.109)	(0.222)	(0.0403)	(0.0581)	(0.0840)
Spec	-0.0000452*	-0.0000856**	-0.000147**	0.00000727	0.0000106	0.0000159
	(0.0000195)	(0.0000328)	(0.0000548)	(0.00000668)	(0.0000125)	(0.0000297)
Age	0.540***	0.683***	1.031***	-0.00519	0.0116	0.0983
	(0.0683)	(0.116)	(0.189)	(0.0217)	(0.0468)	(0.0861)
Age sq.	-0.00514***	-0.00626***	-0.00950***	-0.000127	-0.000327	-0.00132
	(0.000673)	(0.00127)	(0.00202)	(0.000191)	(0.000444)	(0.000782)
NbCoauth				0.457***	0.413***	0.420***
				(0.0195)	(0.0245)	(0.0225)
NbPubYear				0.147***	0.178***	0.238***
				(0.0216)	(0.0400)	(0.0352)
NewASJC				-0.183***	-0.144**	-0.209***
				(0.0245)	(0.0504)	(0.0482)
University F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Triplet F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Intersect	-13.22***	-16.99***	-25.40***	0.252	-0.413	-1.352
	(1.933)	(3.166)	(5.337)	(0.600)	(1.348)	(2.739)
N	5456	1356	1209	5456	1356	1209
adj. R^2	0.555	0.552	0.529	0.883	0.883	0.893

Clustered standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4.7: Results conditional difference-in-differences

	(1) NbPubYear	(2) NbPubYear	(3) NbRepeatCoauth	(4) NbRepeatCoauth	(5) TeamSize	(6) TeamSize	(7) NbCoauth	(8) NbCoauth
SelfEmp	-0.424**		0.0184		-0.405*		-0.350*	
	(0.155)		(0.0509)		(0.196)		(0.159)	
SelfEmpContr	0.0196		-0.0572		0.760		-0.0220	
	(0.106)		(0.0536)		(1.036)		(0.132)	
EntrDum		-0.631*		-0.141		-0.949		-0.767**
		(0.264)		(0.0994)		(0.729)		(0.261)
EntrDumContr		-0.0928		0.0236		-1.028		-0.145
		(0.223)		(0.0956)		(0.615)		(0.240)
NbGrants	-0.234	-0.0373	0.209	0.242	0.0168	-0.216	0.570	0.122
	(0.352)	(0.420)	(0.150)	(0.172)	(0.227)	(0.292)	(0.450)	(0.374)
Spec	-0.0000292**	-0.0000445**	0.000000894	0.00000374	0.00000961	0.0000108	-0.0000220	-0.0000462*
	(0.0000105)	(0.0000140)	(0.00000473)	(0.00000698)	(0.0000283)	(0.0000338)	(0.0000144)	(0.0000191)
Age	0.441***	0.546***	0.0222	0.0457	0.703***	0.576*	0.176**	0.124
	(0.0375)	(0.0817)	(0.0125)	(0.0302)	(0.194)	(0.231)	(0.0551)	(0.0866)
Age sq.	-0.00379***	-0.00431***	-0.000141	-0.000302	-0.00536**	-0.00398*	-0.00102	-0.000158
	(0.000333)	(0.000781)	(0.000117)	(0.000287)	(0.00163)	(0.00159)	(0.000536)	(0.000843)
NbCoauth			0.437***	0.407***				
			(0.0214)	(0.0267)				
NbPubYear			0.141***	0.140***	0.580***	0.502***	1.242***	1.198***
			(0.0274)	(0.0345)	(0.108)	(0.103)	(0.0934)	(0.0969)
NewASJC			-0.174***	-0.152***				
			(0.0223)	(0.0261)				
Individual F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Intersect	-9.596***	-13.25***	-0.726*	-1.415	-18.56***	-15.25*	-5.727***	-4.824*
	(0.996)	(2.020)	(0.295)	(0.747)	(5.204)	(6.870)	(1.277)	(2.113)
N	7760	4817	7760	4817	7760	4817	7760	4817
adj. R^2	0.095	0.074	0.721	0.666	0.032	0.031	0.458	0.451

Clustered standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4.8: Regression results quality adjusted publications

	(1) PubCitw3	(2) PubCitw3	(3) PubCitw3	(4) PubCitw5	(5) PubCitw5	(6) PubCitw5
SelfEmp	-0.210			-1.996		
	(5.424)			(6.291)		
EntrDum		5.438	18.41		6.067	44.52**
		(9.241)	(11.52)		(13.47)	(16.21)
AvgPubPreAe	19.39***	25.83***	17.19**	30.16***	40.36***	5.606
	(3.887)	(7.668)	(6.124)	(5.657)	(11.92)	(4.387)
NbGrants	0.371	-1.017	5.120	-1.395	-1.939	3.648
	(2.124)	(2.833)	(3.301)	(3.193)	(4.346)	(5.352)
Spec	-0.000289	-0.00109	-0.00166	-0.000359	-0.00149	-0.00569
	(0.000497)	(0.00110)	(0.00164)	(0.000629)	(0.00164)	(0.00308)
Age	5.492***	10.63*	11.87	7.827***	16.29*	5.719
	(1.656)	(4.498)	(6.414)	(2.128)	(6.509)	(8.218)
Age sq.	-0.0595***	-0.111*	-0.119*	-0.0876***	-0.170**	-0.0493
	(0.0160)	(0.0446)	(0.0557)	(0.0213)	(0.0656)	(0.0750)
University F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Triplet F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Intersect	-136.6**	-287.2*	-302.3	-185.6**	-429.3*	-149.9
	(47.58)	(130.7)	(195.7)	(60.33)	(187.3)	(237.7)
N	4781	1220	898	4331	1220	515
adj. R^2	0.303	0.353	0.200	0.362	0.373	0.120

Clustered standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4.9: Regression results for the moderation effect of exploration

	(1) NbPubYear	(2) NbPubYear	(3) NbPubYear	(4) NbRepeatCoauth	(5) NbRepeatCoauth	(6) NbRepeatCoauth
SelfEmp	-0.483*			0.0170		
	(0.220)			(0.0661)		
SelfEmp × NbNewASJC	0.281			-0.0471		
	(0.206)			(0.0725)		
EntrDum		-0.298	0.134		-0.220*	-0.0925
		(0.232)	(0.377)		(0.0986)	(0.179)
EntrDum × NbNewASJC		-0.0211	0.112		0.0381	-0.219*
		(0.129)	(0.129)		(0.0903)	(0.0862)
AvgPubPreAe	1.354***	1.258***	1.617***			
	(0.180)	(0.247)	(0.370)			
AvgRepeatCoauthPreAe				0.400***	0.540***	0.493**
				(0.0707)	(0.139)	(0.171)
NbGrants	-0.0347	0.0422	0.114	0.00837	0.0391	0.136
	(0.0906)	(0.0880)	(0.215)	(0.0401)	(0.0587)	(0.0831)
Spec	-0.0000512**	-0.0000749*	-0.000128**	0.00000590	0.00000765	0.0000185
	(0.0000177)	(0.0000292)	(0.0000492)	(0.00000681)	(0.0000131)	(0.0000297)
Age	0.499***	0.635***	1.030***	-0.00155	0.0154	0.0620
	(0.0675)	(0.108)	(0.181)	(0.0221)	(0.0477)	(0.0866)
Age sq.	-0.00475***	-0.00587***	-0.00941***	-0.000170	-0.000387	-0.00101
	(0.000667)	(0.00117)	(0.00192)	(0.000194)	(0.000454)	(0.000800)
NewASJC	0.691***	0.663***	0.681***	-0.184***	-0.150*	-0.134*
	(0.0352)	(0.0689)	(0.0861)	(0.0254)	(0.0611)	(0.0530)
NbCoauth				0.459***	0.414***	0.420***
				(0.0202)	(0.0245)	(0.0222)
NbPubYear				0.140***	0.176***	0.241***
				(0.0247)	(0.0400)	(0.0346)
University F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Triplet F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Intersect	-12.45***	-17.59***	-26.14***	0.282	-0.596	-0.703
	(1.928)	(3.124)	(5.280)	(0.633)	(1.354)	(2.712)
N	5177	1356	1209	5177	1356	1209
adj. R^2	0.622	0.627	0.601	0.885	0.883	0.894

Clustered standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4.10: Results for the effect of seniority

	(1) NbPubYear	(2) NbPubYear	(3) NbPubYear	(4) NbRepeatCoauth	(5) NbRepeatCoauth	(6) NbRepeatCoauth
SelfEmpYoung	-0.617**			0.0744		
	(0.227)			(0.120)		
SelfEmpOld	-0.523			-0.0496		
	(0.360)			(0.0963)		
EntrDumYoung		-0.436	0.490		-0.142	-0.205
		(0.284)	(0.408)		(0.101)	(0.189)
EntrDumOld		-0.551	-0.254		-0.268*	-0.754**
		(0.479)	(0.833)		(0.133)	(0.256)
AvgPubPreAe	1.418***	1.332***	1.713***			
	(0.193)	(0.271)	(0.405)			
AvgRepeatCoauthPreAe				0.375***	0.546***	0.538**
				(0.0627)	(0.141)	(0.177)
NbGrants	-0.0322	0.0741	0.0844	0.00896	0.0395	0.126
	(0.103)	(0.110)	(0.226)	(0.0403)	(0.0586)	(0.0803)
Spec	-0.0000484*	-0.0000822*	-0.000143**	0.00000740	0.00000840	0.0000127
	(0.0000197)	(0.0000330)	(0.0000543)	(0.00000671)	(0.0000132)	(0.0000297)
Age	0.570***	0.681***	1.054***	-0.00572	0.0141	0.110
	(0.0710)	(0.115)	(0.192)	(0.0218)	(0.0476)	(0.0871)
Age sq.	-0.00539***	-0.00621***	-0.00974***	-0.000120	-0.000374	-0.00143
	(0.000702)	(0.00126)	(0.00201)	(0.000193)	(0.000452)	(0.000801)
NbCoauth				0.457***	0.414***	0.419***
				(0.0195)	(0.0246)	(0.0224)
NbPubYear				0.147***	0.175***	0.237***
				(0.0215)	(0.0400)	(0.0348)
NewASJC				-0.182***	-0.141**	-0.209***
				(0.0244)	(0.0509)	(0.0480)
University F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Triplet F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Intersect	-14.03***	-16.98***	-26.58***	0.247	-0.560	-1.903
	(2.008)	(3.185)	(5.479)	(0.598)	(1.393)	(2.757)
N	5177	1356	1283	5456	1356	1209
adj. R^2	0.553	0.551	0.525	0.883	0.883	0.894

Clustered standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4.11: Results for the effect of spell length

	(1) NbPubYear	(2) NbPubYear	(3) NbPubYear	(4) NbRepeatCoauth	(5) NbRepeatCoauth	(6) NbRepeatCoauth
SelfEmpShort	0.207			-0.0494		
	(0.630)			(0.130)		
SelfEmpLong	-0.700**			0.00739		
	(0.260)			(0.0832)		
EntrDumShort		-0.107	0.607		-0.0739	-0.361
		(0.324)	(0.459)		(0.109)	(0.187)
EntrDumLong		-0.823*	-0.0853		-0.295*	-0.390
		(0.358)	(0.620)		(0.117)	(0.244)
AvgPubPreAe	1.418***	1.321***	1.639***			
	(0.193)	(0.266)	(0.401)			
AvgRepeatCoauthPreAe				0.374***	0.543***	0.512**
				(0.0626)	(0.139)	(0.173)
NbGrants	-0.0340	0.0626	0.182	0.00877	0.0355	0.129
	(0.103)	(0.112)	(0.222)	(0.0403)	(0.0582)	(0.0822)
Spec	-0.0000481*	-0.0000828*	-0.000151**	0.00000726	0.00000785	0.0000173
	(0.0000197)	(0.0000320)	(0.0000560)	(0.00000668)	(0.0000131)	(0.0000300)
Age	0.568***	0.685***	1.018***	-0.00531	0.0166	0.0994
	(0.0710)	(0.116)	(0.191)	(0.0218)	(0.0477)	(0.0870)
Age sq.	-0.00537***	-0.00620***	-0.00933***	-0.000126	-0.000382	-0.00135
	(0.000704)	(0.00127)	(0.00204)	(0.000193)	(0.000452)	(0.000800)
NbCoauth				0.457***	0.414***	0.419***
				(0.0195)	(0.0245)	(0.0225)
NbPubYear				0.147***	0.175***	0.239***
				(0.0216)	(0.0397)	(0.0358)
NewASJC				-0.182***	-0.143**	-0.209***
				(0.0245)	(0.0507)	(0.0481)
University F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Triplet F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Intersect	-14.02***	-17.00***	-24.77***	0.250	-0.535	-1.407
	(2.012)	(3.187)	(5.388)	(0.599)	(1.373)	(2.752)
N	5177	1356	1209	5456	1356	1209
adj. R^2	0.553	0.553	0.530	0.883	0.883	0.893

Clustered standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4.12: Results for patent applications

	(1) NbPat	(2) NbPat	(3) NbPat	(4) PatDum	(5) PatDum	(6) PatDum
SelfEmp	-0.0118*			-0.00819		
	(0.00517)			(0.00431)		
EntrDum		-0.0155	-0.00739		0.00426	-0.00667
		(0.0150)	(0.00800)		(0.00958)	(0.00587)
AvgPatPreAe	0.680***	1.474**	0.0651	0.396***	0.720***	0.0394
	(0.183)	(0.482)	(0.0569)	(0.0920)	(0.174)	(0.0405)
NbGrants	-0.00840	-0.0158	0.00971*	-0.00393	-0.00380	0.00851*
	(0.00504)	(0.0103)	(0.00453)	(0.00330)	(0.00476)	(0.00373)
NbPubYear	0.00257**	0.000565	0.00129	0.00241***	0.00142	0.00100
	(0.000828)	(0.00177)	(0.00107)	(0.000678)	(0.00142)	(0.000920)
Spec	-0.00000122*	-0.00000294	-0.00000125	-0.000000856*	-0.00000290*	-0.00000150
	(0.000000541)	(0.00000201)	(0.00000147)	(0.000000376)	(0.00000132)	(0.00000123)
Age	0.00468*	0.00445	0.00532	0.00298*	0.00338	0.00371
	(0.00231)	(0.00492)	(0.00375)	(0.00138)	(0.00314)	(0.00316)
Age sq.	-0.0000404*	-0.0000261	-0.0000605	-0.0000298*	-0.0000359	-0.0000442
	(0.0000198)	(0.0000480)	(0.0000336)	(0.0000122)	(0.0000287)	(0.0000288)
University F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Triplet F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes	Yes	Yes
Intersect	-0.127*	-0.118	-0.101	-0.0743	-0.0779	-0.0541
	(0.0636)	(0.132)	(0.142)	(0.0378)	(0.0891)	(0.126)
N	5177	1356	1209	5177	1356	1209
adj. R^2	0.094	0.162	0.002	0.089	0.125	0.013

Clustered standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figures

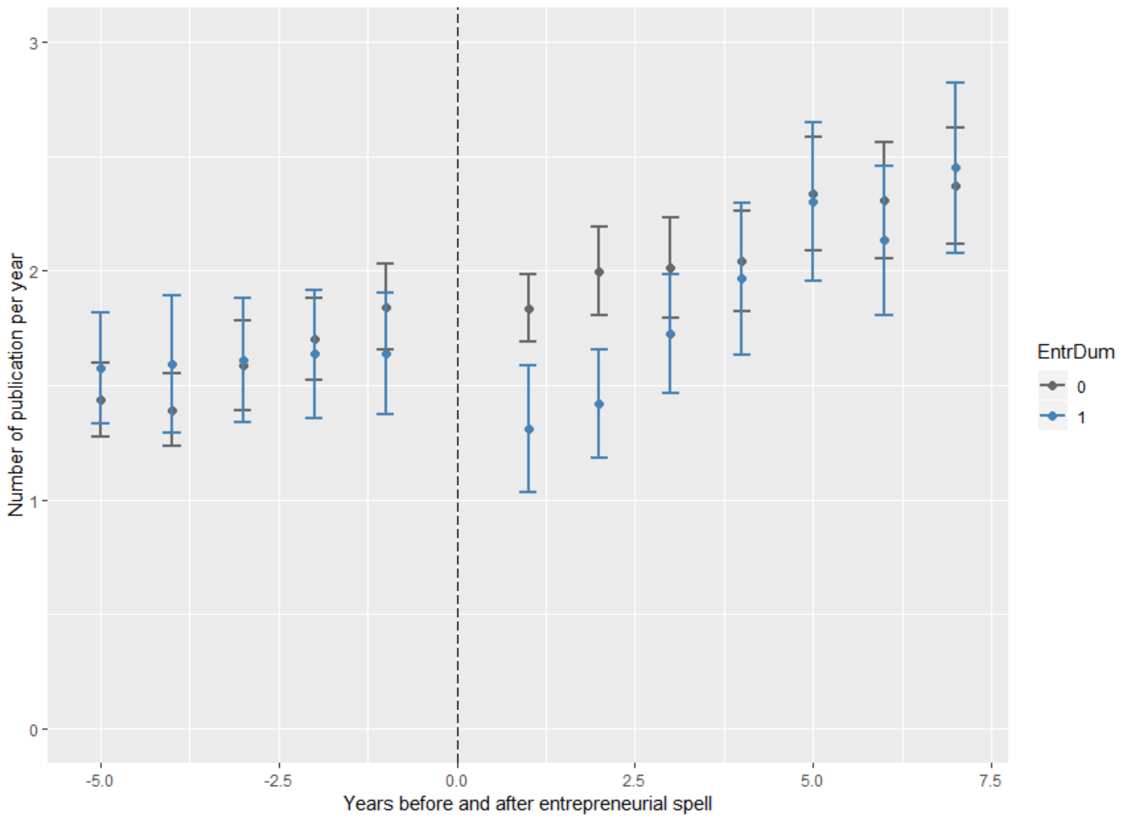

Figure 4.1: This figure depicts the raw mean differences in the yearly publication output between entrepreneurs and their matched controls, in the years before and after the entrepreneurial spell. Years during the spell are excluded.

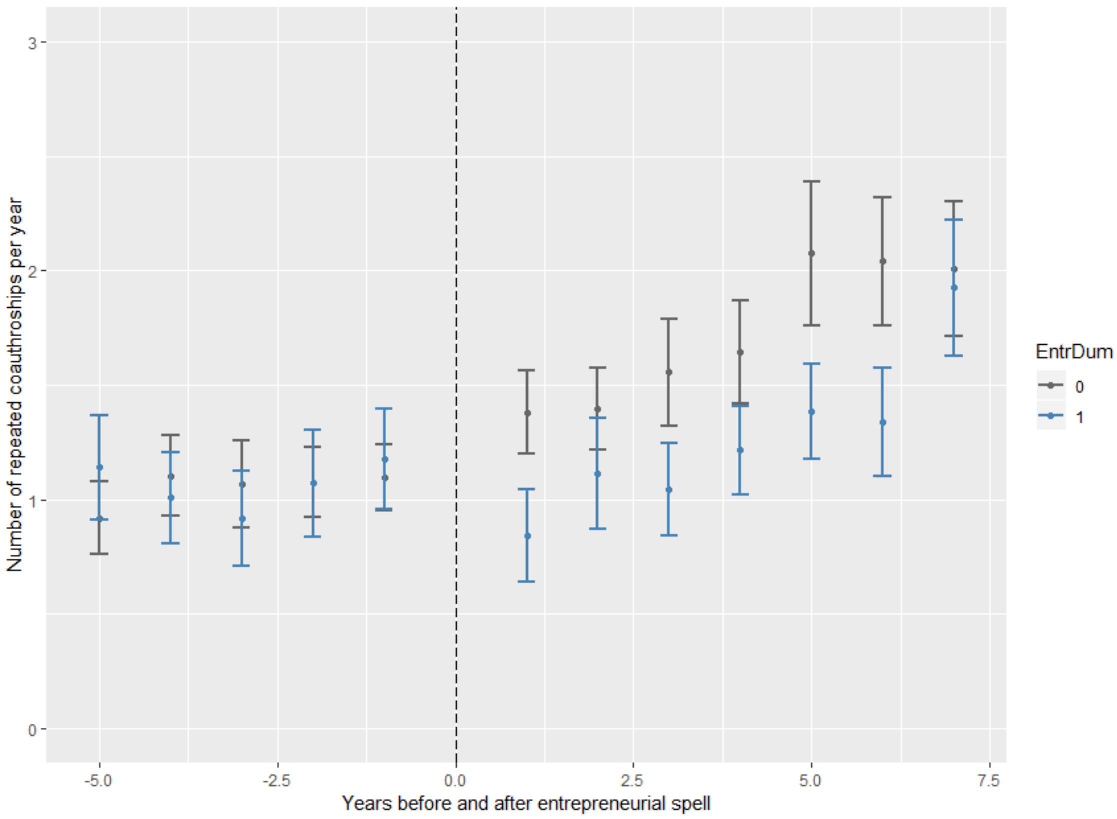

Figure 4.2: This figure depicts the raw mean differences in the yearly number of repeated co-authorships between entrepreneurs and their matched controls, in the years before and after the entrepreneurial spell. Years during the spell are excluded.

TITLER I PH.D.SERIEN:

2004

1. Martin Grieger
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3. Morten Knudsen
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4. Lars Bo Jeppesen
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7. Henriette Hallberg Thygesen
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