Peeking into the Black Box of Researcher Mobility and Knowledge Diffusion

Effects of Different Mobility Types on Individual Researchers

Dissertation

zur Erlangung des akademischen Grades
Doktor der Wirtschafts- und Sozialwissenschaften
(Dr. rer. pol.)

vorgelegt am 18. März 2020
im Fachbereich Wirtschaftswissenschaften der Universität Kassel

Datum der Disputation: 28. Juli 2020, Kassel

von

Rasmus Bode

Erster Gutachter: Prof. Dr. Guido Bünstorf

Zweiter Gutachter: Prof. Dr. Ivo Bischoff

Externe Gutachterin: Prof. Dr. Hanna Hottenrott

Acknowledgements

This thesis could not have come into being without the help and emotional support of a large number of people. First and foremost, I would like to thank Guido Bünstorf, my doctoral advisor, for his unwavering support. For many years, he served as a role model, not only in regards to academia, but also as an open, direct, solution-oriented human being who is always able to differentiate between the personal and the professional level. Guido, you give true meaning to the term "Doktorvater".

I would also like to thank Ivo Bischoff and Hanna Hottenrott for their reviews of this thesis, and, along with Guido, Sylvia Veit and Björn Frank, for their participation in a rather unusual dissertation defense (due to COVID-19 and the resulting restrictions).

Special thanks go out to Dominik Heinisch, who acted as my older "Doktorbruder". Having Dominik and Guido as my co-authors was extremely beneficial for me. It was a pleasure to work with Dominik, share an office with him, and gain him as a friend.

I always enjoyed working in the EPIE-group and at the WISKIDZ-project, and I am deeply grateful to my (former) colleagues within and around the group for creating a positive, creative and productivity-enhancing work environment, be it at the lunch table, at internal seminars or after hours. In addition to Guido, Ivo and Dominik, my thanks go out to Stefan Krabel, Matthias Geissler, Nicolas Winterhager, Ann-Kathrin Blankenberg, Stephan Bruns, Igor Asanov, Johannes König, Francisco Flores, Matthias Kapa, Merve Kiliçkan, Maria Mavlikeeva, Andreas Rehs, Maria Theißen, Gerd Stumme, Anne Otto and Tom Hanika. I would also like to thank the office team for their eternal patience while dealing with all kinds of problems thrown at them.

Björn Frank lead me on my way to microeconomics, gave me guidance during my undergrad-years and at some point became the man to beat at Doppelkopf. For that, I am thankful.

Dominik, Stephan, Benjamin Schwanebeck and Gunnar Gutsche turned out to be the kind of friends with whom I could not only have enjoyable evenings, but who, due to their similar experiences, were of great emotional support during my PhD years. I cannot be thankful enough for having friends like them.

Last but not least, I would like to send special thanks to my friends and family, who supported me through all these years. Knowing that my parents always had my back was of immeasurable value. And, most of all, Eva. Without you, all of this would have been pretty dull.

Rasmus Bode

September 2020

Summary

This dissertation thesis presents four studies on the relevance of individuals' mobility for the dissemination of knowledge. They add to the literature on the economics of science and innovation as well as regional economics. Previous literature has shown researcher mobility to be an important driver of knowledge diffusion and, subsequently, the creation of new knowledge. However, different mobility types are often correlated and hard to differentiate. This thesis tries to help advance this research strand, in highlighting the importance of different mobility types, and their reasons and effects on the individual researcher's level.

The first study presented in this thesis shows that there was a demand shock for junior researchers on the German academic job market after German reunification. It goes on to show that there did not seem to be significant differences between researchers who stayed in Western Germany and those who ventured East, and that going East did not seem to have significant effects on future researchers' productivity. This is argued to show that entrepreneurial behavior (as signified by going East) is not rewarded in academia.

The second study presented in this thesis looks at a different type of mobility. Here, the more abstract mobility in the space of ideas, thematic mobility, is regarded. It shows that among highly qualified junior researchers in physics, thematic mobility seems to be neither punished nor rewarded in academia.

The third study is of a descriptive nature, and shows the prevalence of specific scientific families, as defined by advisor-advisee relationships, in German business studies. It states that tacit knowledge that is passed through the generations of researchers as well as advisors' networks could be drivers of this circumstance, and calls for further research on the topic.

In the fourth and final study in this thesis, a natural experiment that occurred after the end of World War II is used to show that relatively speaking, cognitive proximity between two interacting agents seems to be much more important for a successful knowledge transfer than social proximity. It also shows once more that knowledge flows are always bidirectional, and a one-way knowledge transfer is hard, if not impossible, to execute.

Zusammenfassung

In dieser Dissertationsschrift werden vier Studien vorgestellt, die sich mit der Relevanz individueller Mobilität von Forschern für die Diffusion von Wissen beschäftigen. Sie können in das Grenzgebiet zwischen Wissenschafts-, Innovations- und Regionalökonomik eingeordnet werden. In der bisherigen Literatur wurde gezeigt, dass Mobilität von Forschern ein wichtiger Treiber der Wissensdiffusion und -kreation ist, wobei zwischen verschiedenen Mobilitätstypen unterschieden werden kann, die jedoch oft stark korreliert und schwer auseinanderzuhalten sind. Ziel dieser Arbeit ist es, verschiedene Mobiltätstypen sowie ihre Gründe und Effekte auf dem individuellen Level besser zu unterscheiden.

In der ersten Studie wird gezeigt, dass die deutsche Wiedervereinigung zu einem Nachfrageschock auf dem wissenschaftlichen Arbeitsmarkt führte. Weiter wird gezeigt, dass sich Forscher, die das Wagnis eingingen, eine Berufung nach Ostdeutschland anzunehmen, nicht signifikant von denen unterschieden, die in Westdeutschland blieben, und dass auch nach der Berufung keine Unterschiede in der Produktivität gefunden werden konnten, was als Zeichen dafür interpretiert wird, dass unternehmerisches Handeln auf dem wissenschaftlichen Arbeitsmarkt nicht belohnt wird.

In der zweiten Studie wird thematische Mobilität, also die Mobilität zwischen Themenfeldern, betrachtet, und es wird gezeigt, dass thematische Mobilität unter hochqualifizierten Nachwuchsforschern in der Physik weder belohnt noch bestraft wird.

Die dritte Studie zeigt deskriptiv die Prävalenz einiger wissenschaftlicher Familien in der deutschen Betriebswirtschaftslehre auf. Es wird argumentiert, dass dafür sowohl das Weiterreichen von implizitem Wissen als auch die Vernetzungen des Doktorvaters/der Doktormutter relevant sein können, und es wird zu weiterer Forschung aufgerufen.

In der vierten Studie wird mit einem britischen Programm zur Wissenserlangung nach dem Zweiten Weltkrieg ein natürliches Experiment betrachtet um zu zeigen, dass kognitive Nähe für den Wissenstransfer wichtiger ist als soziale Nähe, und dass Wissenstransfers immer zweiseitig sind.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 The Economic Relevance of Knowledge Production

Economic growth is driven by technological change (Solow, 1956; Romer, 1990), and the facilitation of innovation has thus long been a focus of economic policy. Innovation relies on the recombination of factors of production, and this new recombination being brought to the market (Schumpeter, 1911). Similarly, knowledge production can be seen as a recombination of existing knowledge (Nelson and Winter, 1982). The knowledge that is recombined in the innovation process can stem from different sources, usually either prior inventions or the more basic scientific research. Especially in newly emerging fields, scientific research can make up a major part of the knowledge base used in the development of new technologies (Narin and Noma, 1985).

While there certainly are effects of knowledge recombination on the macro-level, with whole economies depending on innovative activities, understanding this process requires not only a look at the institutions that foster or deter growth through innovation (Nelson, 2008), but also on the individual researcher's level (Sauermann and Cohen, 2010). A large part of economic research on the topic of knowledge production has focused on industrial research, with innovations as the outcome of inventions and entrepreneurial processes. A majority of these processes takes place in (big) firms. In 2018, 71 per cent of all patents filed at the European Patent Office were filed by large companies (European Patent Office, 2019). Due to the complex nature of innovative processes, it is not surprising that these are mostly bundled in firms, where transaction costs can be minimized and procedures streamlined (Coase, 1937). However, innovations are more and more based on scientific research (Stephan, 1996), and the process of knowledge production in the academic sector cannot be disregarded in economic studies of innovation. Foray (2004) and Powell and Snellman (2004) argue that modern economies are at an increasing rate becoming more reliant on knowledge, and less so on physical capital or natural resources, which again points to an increasing importance of scientific research for economies' success.

At the core of knowledge production processes, be it in scientific or industrial research, are researchers who recombine existing knowledge. A look at individual researchers is imperative for a proper understanding of the process of knowledge production, and comes with a number of insights for economists. Due to the cumulative nature of knowledge production, careers in research are quite specific, and require certain personal characteristics of researchers. The major input factor in the knowledge production function is previous knowledge, and at the firm/individual level, absorptive capacity (Cohen and Levinthal, 1990) is needed in order to properly process this prior knowledge. Absorptive capacity is generated through individuals' cognitive abilities and the scope and diversity of prior knowledge (Cohen and Levinthal, 1990). At least in science, where financial incentives are limited, researchers also need some form of intrinsic motivation, a 'taste for science' (Roach and Sauermann, 2010) to stay active in research.

The peculiarities of academic research have led to the emergence of the economics of science (Stephan, 1996), a field in which not only the academic labor market, which is highly competitive and mostly merit based (Merton, 1973; Dasgupta and David, 1994), is focused on, but also knowledge production processes on the individual level. One matter that has been extensively studied in innovation research as well as in the economics of science is the importance of distances. The idea that knowledge spillovers are localized can be traced all the way back to Alfred Marshall (1920), but is still relevant in modern times, even though modern communication techniques should theoretically make geographic distance less of an issue for the transfer of knowledge. This leads to the assumption that a large part of the knowledge that needs to be recombined in order to produce new knowledge is of a tacit nature (Polanyi, 1966). It has been shown that not only geographic distances, but also the stock of common prior knowledge (Cohen and Levinthal, 1989) as well as social ties (Breschi and Lissoni, 2009) are important for knowledge transfers between individuals, but disentangling these factors has proven a difficult task.

Due to the competition for priority in scientific publishing (Merton, 1957) and the resulting 'publish or perish'-nature of the scientific job market (Weingart, 2005), the individual researcher's success in form of publications that get cited by his or her peers is inherently important for them to be able to further contribute to the production of new knowledge. To get a better understanding of the knowledge production process, one thus has to understand how, among other factors, the aforementioned different types of distances and individual researchers' mobility within the space that defines these distances influence their respective chances for success. In this thesis, I aim to add to the literature explaining the effects of different mobility-types and -events on the individual researcher.

To properly understand the knowledge production process, empirical studies are necessary. While theoretical considerations are important for a general idea about a certain topic, observational studies are needed to understand the finer details. In an ideal world, field experiments with proper randomized control trials could be executed to understand the specifics of the knowledge production process. In practice, though, these field experiments are hard to implement and, among other issues, suffer from missing control over external factors, missing information on the individual level and, sadly, very high cost. In the studies that make up this dissertation, other forms of observational data are thus utilised. In two of the studies, natural experiments are used to infer causal relationships. One study uses cross-sectional data, which is not optimal for causal inference, but still gives a better understanding of the correlations and, using certain assumptions, gives some ideas on how the causalities may lie. The fourth study purely relies on descriptive data, which can later be used as the basis for further research.

These studies completely rely on secondary data sources. A large part of the work that went into them was to collect and process data in a way that allows for a high credibility of the analyses. Using secondary data, as opposed to survey data, comes with the disadvantage of not being able to control for unobservable personal characteristics, which may be controlled for in surveys. However, secondary data, if collected correctly, does not suffer from problems such as response bias and ex-post-rationalising. These studies should thus be seen as complementary to studies with different research designs.

To visualize knowledge production and knowledge trails, the study in chapter 5 of this dissertation uses patent-application and -citation data and two of the remaining studies use comparable data for scientific publications. Before this data can be used, the sample has to be specified, and other data sources are needed to identify the researchers of interest and to collect other relevant data. The studies in this dissertation thus rely on a number of data sources, the utilization of each of which came with its own advantages and challenges.

For the first study, a number of data sources was used to, in a first step, identify German researchers who received a *Habilitation* degree between 1981 and 2000 in physics, economics or business administration. The majority of these *Habilitationen* was identified through the catalogue of the German National Library (*Deutsche Nationalbibliothek*, DNB), which collects all German publications. The *Schriftenreihe H* of the DNB contains information on all publications made through German universities. This includes all dissertations since 1970 (because since then, the publication of the thesis is obligatory for all German dissertations), and a portion of the *Habilitationen.* Unfortunately, since there is no federal rule for the publication of *Habilitationen* in Germany, the DNB-data does not fully cover *Habilitationen.* Other data sources thus had to be utilized to expand the sample. The experiences from the data collection in this study led to work on a register of German *Habilitationen* that is made available to the research community. For the thus created sample of close to 1,700 *Habilitierte*, data on dissertations was found through the DNB catalogue, data for appointments to professorships was taken from *Deutsche Universitätszeitung* (duz) and *Kürschners Deutscher Gelehrtenkalender*, and publication records were linked through Thomson Reuters Web of Science (WoS), Elsevier Scopus and the German WiSo database for physicists, economists and business administration scholars, respectively. Each of these databases comes with some challenges. Disambiguation is not an easy task, especially considering that a majority of the entries in WoS and Scopus only come with first name initials for the authors, that the WiSo database is inflated by data on working papers, grey literature and double/triple entries with different spellings, and that authors within these datasets are not properly disambiguated. Data cleanup thus was a major task for this study, and included manually checking a mid-to-high-5-figure amount of possible matches for their fit.

The data for the second study consists of physicists who received funding through Emmy-Noether grants from the German research foundation (*Deutsche Forschungsgemeinschaft*, DFG). This data is readily available through the DFG's online-database DFG GEPRIS. It was again linked to dissertation data from the DNB, and additional information about the researchers was found through online CVs. As for publication data, WoS data was utilized once more. Since in this study, the focus was on thematic mobility, it was essential to find all publications by each author, especially the ones that are thematically different from their other publications. This made the linkage more difficult, because algorithms that rely on co-citations or other similarity measures to find positive/negative matches could not be utilized, since they would have run a high risk of excluding the publications of interest. The original linkage thus had to be very broad, and about 50,000 possible matches had to be checked manually.

The third study looks at the prevalence of scientific families in a sub-group of German business administration. The starting point of this study was a member list of the *WK ORG*, the subsection of the *Verband der Hochschullehrer für Betriebswirtschaft* (VHB) for organisational theory. This data was again linked to dissertation data from the DNB. One part of the WISKIDZ-project, through which this dissertation was mainly funded, was to generate the BibSonomy Genealogy (https://www.bibsonomy.org/persons), an online tool through which dissertations of graduates can be linked to those of their advisors. For some members of the WK ORG, advisor-advisee relationships were entered in BibSonomy Genealogy. To get a more complete picture, acknowledgements of dissertation theses had to be manually searched at the DNB for references to the advisor.

In the fourth study, a sample of German researchers was identified through lists acquired from the British National Archive. They were taken to the U.K. after the end of the second World War to be questioned as part of the BIOS-program. For these researchers, patents were manually identified in DEPATISnet, the online database of the German patent office. Similarly, patenting records were created for a Swiss and a German control group. Patents were also linked to PATSTAT to acquire information on citations. Working with the historical data in this study again required a lot of manual work, because most of the data was not digital, or not machine-readable.

Across these four studies, a large amount of effort went into data-collection and -processing. While this work took up a majority of the time that I worked on this dissertation project, it resulted in new, reliable datasets that could be used to shed some more light on the effects of different mobility-types on researchers' success and the diffusion of knowledge.

This dissertation is structured as follows. The remainder of this chapter is used to give an introduction to the literature on mobility types and knowledge diffusion on the individual level. The four following chapters each contain one study.

Chapter 2 consists of a study that was co-authored with Prof. Dr. Guido Buenstorf[1]. In this study, we aim to show whether or not entrepreneurial behavior is rewarded in academia. In order to do so, we first show that in physics as well as in economics and business administration (in the latter less so than in the other two disciplines), there was a demand shock on the German academic job market for junior researchers after the German reunification. We do so by showing that the chances of being hired as a professor are relatively high for researchers who completed their *Habilitation* shortly before or after reunification, as compared to those who came before and after them. We argue that taking a faculty position at East German universities right after reunification can be interpreted as entrepreneurial behavior. Due to the complete restructuring of the East German academic system, opportunities may have opened up for early movers, but an early move was probably also connected to a high degree of uncertainty. This corresponds to the situation possible entrepreneurs face. So, in this study, we are interested in the effects that mobility into uncertain, highly shapeable environments had. We can show that researchers who went East were no less productive than their peers who stayed in the West, and that very early adopters in physics were even more productive than their counterparts who stayed West. We cannot find any effects of going East on future research productivity, but we can show that in economics, researchers who went East were less likely to receive further calls for tenure

[1]University of Kassel, Institute of Economics and INCHER-Kassel (Germany); University of Gothenburg, Institute of Innovation and Entrepreneurship (Sweden)

than their Western counterparts. All of this points to the entrepreneurial behavior of scientists not being rewarded in the German academic system.

In the study in chapter 3, I take a look at the effects of voluntary thematic mobility on researchers' acceptance within the scientific community. I construct a sample of highly qualified junior researchers in German physics and, using text-based measures, show to what degree these researchers were thematically mobile in their postdoc-phase, as compared to their dissertation phase. I argue that among this group of highly qualified researchers, thematic mobility is highly likely to be voluntary, and I can show that it does not seem to be significantly related to the amount of citations they receive or their likelihood to win scientific awards. I interpret this as a sign for voluntary thematic mobility of researchers who are qualified to calculate risks and rewards of such ventures not being punished. I call for more research on the effects of thematic mobility in which more efforts are taken to take the causes for thematic mobility into account.

In chapter 4, I present a study in which I identify academic families in a subsection of the German Academic Association for Business Administration (*Verband der Hochschullehrer für Betriebswirtschaft*, VHB). I show that certain professors seem to be better able to advise doctoral students who later become professors (at universities all over Germany) and again advise doctoral students, thus expanding their "scientific family" better than others. This leads to the prevalence of descendants of certain professors within scientific communities. The study is purely descriptive, but I take it as support for the theory that the home department plays a big role in the formation of junior researchers' future careers.

Chapter 5 presents a study co-authored with Guido Buenstorf and Dominik Heinisch. This study aims to disentangle the effects that cognitive and social/institutional proximity, which are oftentimes closely linked to geographic proximity and are usually a consequence of personal choice, have on knowledge diffusion. We utilize data on a British post-WW2 intellectual reparations program, in which German researchers were moved to the U.K. for a limited amount of time to be questioned by British officials and experts. We show that, even though the British experts were requested not to let the Germans know anything about their research and could be considered socially distant from them, the detained Germans' likelihood to interact with U.K. partners as well as their post-detention productivity were increased by the stay abroad. Meanwhile, no post-detention cooperation between formerly interned Germans, who were socially much closer to each other but cognitively more distant, could be found. Utilizing the unique nature of this natural experiment, we come to the conclusion that cognitive proximity plays a much bigger role in knowledge diffusion than social/institutional proximity.

Chapter 6 concludes the dissertation.

1.2 The Knowledge Production Process and the Importance of the Individual Researcher and Different Mobility-Types

1.2.1 Theoretical Considerations

To understand the economics of knowledge production, one first has to understand the meaning of knowledge as an economic good. Foray (2004) stresses the importance of the differentiation between knowledge and information. While information can be replicated at next to no cost, and can thus be seen as a public good, knowledge, which according to Foray (2004, p.4) "empowers its possessors with the capacity for intellectual or physical action", can be far more complex. Knowledge that cannot be codified (at a reasonable cost) is called *tacit knowledge* (Polanyi, 1966). The passing of tacit knowledge from one person to the other is a non-trivial act. Traditionally, personal interaction has been seen as the only way of passing tacit knowledge; however, codification may be achieved within a group of people that share the same "language" (Foray, 2004). In other words, some kind of common knowledge is needed to pass knowledge from one person to another. This goes in line with the idea of cognitive proximity playing a role in knowledge transfers (Boschma, 2005; Huber, 2012). It also fits the idea that knowledge may be a club good, which acts as a public good within a restricted group of people who are connected through social ties, but are not necessarily geographically close to each other (Breschi and Lissoni, 2001).

The fact that the production of new knowledge heavily relies on the existing knowledge stock necessitates an evolutionary perspective for the modeling of knowledge creation. Especially in the economics of innovation, the modeling of innovative activities has been applied in evolutionary frameworks (Romer, 1990; Witt, 1993; Metcalfe, 1994). Innovative firms stand to gain competitive advantages by being the first ones to introduce new technologies, which on the other hand comes at a cost and with a certain risk, which is why modeling firms' behavior over a number of time periods makes sense. The payoff for this type of risky behavior depends on the reward system that is set in place. Were knowledge a public good, then costly investments into this public good would not pay off, due to the marginal cost of knowledge production far outweighing the marginal cost of its use, which is zero (Foray, 2004). Since, for the aforementioned reasons, knowledge production leads to economic progress, it needs to be incentivized. In the private sector, this incentivization takes place in the form of the granting of intellectual property rights, which can have direct monetary effects (Foray, 2004). In public research on the other hand, a reward system is set in place where priority is rewarded through recognition among peers (Merton, 1957). This, if at all, only has indirect monetary effects through better chances to receive tenured or better equipped positions. Both of these systems lead to the publication of new findings, either through patents or through scientific publications, which helps in the diffusion of knowledge. No matter if they work in the industry or in the public sector, researchers need to always aim to make new relevant discoveries that can be published in one of the former ways, which subsequently helps them advance their careers.

In addition to the reward system mentioned above, the academic job market is defined by a relatively high number of junior researchers who compete for a rather small and fixed amount of tenured positions (Fox and Stephan, 2001). As a result, the supply side (meaning junior researchers looking for a permanent position) is relatively susceptible to changes in demand and supply (e.g., Borjas and Doran, 2012). This, in combination with the fact that quantity and quality of researchers' work can be estimated through publication output and citations (although these measures come with their own problems), opens up many possibilities for research on the academic job market. While tenured researchers are less affected by the high competition on the academic job market, junior researchers are all the more under pressure. Three of the four studies presented in this dissertation thus look at the academic job market, focusing on, or at least taking into account, specifics in the PhD- or postdoc-phase.

1.2.2 Geographic Mobility and Knowledge Diffusion

An entire strand of literature originated from Alfred Marshall's (1920) notion that knowledge spillovers are localized, and that throughout history, industries have developed locally and stayed local, because for people active in the same field and located close to each other, "[t]he mysteries of the trade become no mysteries; but are as it were in the air" (Marshall, 1920, p. 225). Here, the relevance of cognitive distance already becomes apparent. While Marshall (1920) goes on to argue that even children pick up on a lot of the knowledge that surrounds them, and thus ensure the existence of the specific industry within the region, he also acknowledges that it is experts presenting each other with ideas and further building on each other's ideas that advance and further add to a localization of specialized industries.

Around 1960, two pieces of work were published that had a strong impact on the economics of knowledge production. Kenneth Arrow (1962) introduced a model for endogenous economic growth, in which experience with production in a specific industry helps solve the problems that arise due to the act of production itself, leading to continuous growth under the right circumstances. Around the same time, the term *tacit knowledge* was defined by Michael Polanyi (1958; 1966). It describes the type of knowledge that can only be acquired through a learning-by-doing process, and cannot easily be codified. Even though they approach the matter from two completely different angles, both Arrow and Polanyi share the idea that know-how acquired through learning-by-doing is immensely important. This adds some explanatory power to the idea of localized knowledge spillovers, because tacit knowledge by definition cannot be easily shared without both the teaching and the learning party being located at the same place.

All of these considerations lead to the empirical research on the localization of knowledge spillovers. Jaffe et al. (1993) first used patent citations as an indicator for knowledge spillovers, and were able to show that new patents are much more likely to be cited locally (even when looking at the rather small standard metropolitan statistical areas in the U.S.) than should be expected if location did not play a role. Shortly thereafter, Jaffe and Trajtenberg (1996) again used patent citations to track knowledge spillovers, this time from universities to companies. They show that this type of knowledge flow is also much more likely to take place on a local level than on a global one. Helmers and Overman (2017), using the establishment of a large and expensive research facility in the U.K. and its impact on related research, show that within science, knowledge spillovers are strongly localized as well.

The local nature of knowledge spillovers further supports the idea that personal interaction is imperative for the transfer of knowledge. Thus, researcher mobility plays a big role in the diffusion of knowledge. However, geographic proximity may not be enough. Boschma (2005) argues that one should additionally take cognitive, organizational, social and institutional proximity into account. While the latter three types can be argued to be somewhat closely related, the first one is a separate, quite important issue. A researcher's or firm's absorptive capacity is, as mentioned above, defined by the scope and diversity of their prior knowledge (Cohen and Levinthal, 1990). Interacting with an expert of a certain field can only be fruitful if one is able to understand what they are talking about, which requires a stock of common prior knowledge. Boschma (2005) further argues that most of the mentioned proximity types are only useful up to a certain degree, and start to become detrimental afterwards. This may be especially relevant for cognitive proximity, where too much proximity would mean that both interacting parties have the same stock of knowledge and thus a lack of sources for novelty. This is supported by further studies on the subject (e.g., Broekel and Boschma, 2012; Fleming, 2001; Nooteboom et al., 2007).

Agrawal et al. (2006) demonstrate the importance of social ties. Using patent citations, they show that researchers who move from one place to another act as a channel for knowledge from their new location back to their old location. They interpret this as a sign for existing social ties being able to overcome the difficulties posed by geographic distance. Franzoni et al. (2014) show that scientists who move from one country to another experience an increase in the impact factor of their research, arguing that this is caused by them having the opportunity for new knowledge recombinations, while remaining somewhat in the same field. A number of studies looks at researcher mobility, usually finding positive effects of mobility from one institution to the other, even when mobility takes place within the same country (e.g., Fernández-Zubieta et al., 2016; Ejermo et al., 2019).

Geographic mobility of researchers thus seems to have positive impacts on the spread of knowledge, and also on the mobile researcher. A distinction of different proximity measures seems important, and a number of studies have shown their importance. However, these proximity-types are often interlinked, and a distinction of the different types has thus proven difficult in the past (Broekel and Boschma, 2012; Huber, 2012; Crescenzi et al., 2016).

1.2.3 The Impact of the Home Department

Whether or not a researcher is mobile depends on a number of factors. Scientists however have one career stage in which the foundations for their future work are laid, and in which, among other factors, their attitude towards different mobility-types is shaped. This is the PhD training stage. During this stage, junior researchers take their first steps in conducting their own research. Due to the importance of tacit knowledge in science, not only in regards to the research area itself, but also in regards to matters like publishing of scientific papers and possible strategies on the academic job market, they highly depend on interactive learning in this career stage. A PhD student's strongest influence usually is their PhD advisor. This senior researcher's task is to best prepare their advisees for a scientific career. However, there are significant differences in how advisors go about this task, and how they in turn shape their advisees' future careers.

For a sizeable amount of PhD students, attitudes towards a career in science versus a career in the industry have been shown to change during their studies (e.g., Roach and Sauermann, 2010; Sauermann and Roach, 2014). Using survey data, Roach and Sauermann (2017) show that 25 per cent of junior researchers lose interest in an academic career, which they attribute most strongly to a declining interest in doing basic research and a decline in the appreciation of the freedom to choose research projects. While some of these changes may be due to the PhD students gathering information during their studies, and maybe being disillusioned in regards to their appreciation of a scientific career, the role of the advisor and the department in these changes have to be taken into consideration. Multiple studies have shown that this is indeed important. Via the advisor-advisee-relationship, non-codified knowledge that helps establish careers in academia is passed through the generations of researchers

(Malmgren et al., 2010; Buenstorf and Geissler, 2014). Hottenrott and Lawson (2017) show, among other factors, that a department's strength of industry ties positively correlates to its PhD students' probability to leave academia and work in the industry, while a department's focus on basic research is positively correlated to their likelihood of staying in academia. Both of these career paths are important for the diffusion of knowledge. While researchers remaining in academia further produce and spread knowledge within the academic system in the ways mentioned above, junior researchers who get hired by private firms to conduct industrial research constitute an important channel for knowledge flows from universities to the industry (Cockburn and Henderson, 1998; Zucker et al., 2002; Buenstorf and Heinisch, 2020).

The socialization of junior researchers thus plays a major role in how future knowledge is generated and spread. It is thus important to see in detail how prevalent scientific families are in science. If tacit knowledge passed through the generations of researchers is as important as previous work may suggest, one could fear that in certain disciplines, the concentration of researchers from the same background becomes too high at some point, reducing diversity and thus the chances to come up with revolutionary new ideas.

1.2.4 The Reasons for and Effects of Thematic Mobility

While so far, the consensus seems to be that diversity in science is needed for the further advancement of the knowledge frontier, the question remains how such diversity can best be achieved. Since a stock of tacit knowledge is needed to be able to conduct proper research, diversity needs to come from within the system. This means that it is necessary for active research to shift the focus of their research in order to advance science. This kind of diversity in thinking can be defined as thematic mobility, as in mobility within the space of ideas. A researcher's thematic mobility may lead them into an existing field that is only new to them, in which they then can come up with new ways of recombining their previously established knowledge with the existing knowledge in the new field. Alternatively, in a more extreme case, it may lead them to develop a completely new field. The advent of computer science as its own discipline came only after mathematicians pushed the boundaries of what could be done using their long developed tools further and further. Thematic mobility is thus believed to be a driver of major innovations and in turn economic progress (Grabher and Stark, 1997). It is also argued to enhance researchers' creativity and productivity (Kuhn, 1962; Stirling, 2007). At the same time, thematic mobility comes with uncertainty, and researchers may try to make a safe bet by becoming highly specialized and refusing to think outside the box (Gieryn, 1978; Ziman, 1987). Additionally, the presence of paradigms in science (Kuhn, 1962) might deter scientists from being thematically mobile for fear of missing acceptance within the scientific community (Bruce et al., 2004; Yegros-Yegros et al., 2015).

To understand the effects of thematic mobility on a researcher(in whichever form), one first has to understand the causes for it. Here, push- and pull-factors can be differentiated. Push factors are inherent to the researcher, and are usually hard to observe. If a researcher chooses to be thematically mobile without any extrinsic motivation, they usually do so out of curiosity, or because they hope to gain a better understanding by looking at the bigger picture. It is also possible that they hope to become known as the trailblazer for a new research field (Gieryn, 1978; Huutoniemi et al., 2010; Lawson and Soós, 2014).

Typical pull factors that cause thematic mobility are changes in demand or supply on the academic job market, for which there can be a myriad of reasons. As was already discussed in section 1.2.1, competition on the academic job market is high, because a large number of junior researchers try to enter, and tenured positions are rare. This pressure also manifests itself in the competition for funding of research projects and publications in highly reputed journals (Stephan, 1996). Researchers must thus be able to adjust to changes in supply or demand on the academic job market in order to maximize their chances for success. The most direct factor can be a research institute directing a researcher to change their research focus (Crane, 1965). While this can happen in private labs or public research offices, this is less likely to happen at universities, where researchers are usually more free in the choice of their research topics. A slightly less direct way in which researchers can be moved to be thematically mobile is changes in funding. If a funding line runs out and the researcher depends on external funding, they have to find a new funding line, which usually requires some form of thematic changes (Garvey and Tomita, 1972). Researchers can also be motivated to do research on a new-to-them topic by a substantial increase in funding for this type of research (Myers, 2018). A government's focus on competitive vs. block-funding can also have effects on the research focus of researchers, and these effects are different for differently reputed groups of researchers (Wang et al., 2018). The pull factors described so far all stem from the demand side on the academic job market. However, there is also the possibility of changes in supply affecting researchers' thematic focus. Such supply shocks can make great natural experiments, the study of which helps in understanding thematic mobility better. Studies in the past have looked at the effect of an influx of soviet scientists into the U.S. job market of mathematicians after the fall of the Soviet Union, which lead to American mathematicians moving their research focus away from the fields that experienced an increase in supply (Borjas and Doran, 2015a), or at the death of (star-)scientists opening up space for researchers from outside the field (Azoulay et al., 2019) or for the dead scientists' former students (Furman and Heinisch, 2019).

Studies on the effects of thematic mobility on researchers have been inconclusive, so far. This is partly due to the absence of a clear definition of what can and what cannot be considered thematic mobility. A number of studies look at thematic mobility in the form of interdisciplinary research projects. Here, positive (Steele and Stier, 2000; Kwon et al., 2019; Okamura, 2019), negative (Larivière and Gingras, 2010; Wang et al., 2017) or non-linear (inverted-U-shaped) (Uzzi et al., 2013; Yegros-Yegros et al., 2015) effects of interdisciplinarity of publications on received citations have been found, and some studies found no effects at all (Rinia et al., 2001; Adams et al., 2007). A major problem with these studies is that they do not take the reason for thematic mobility into account (although, since all of them look at interdisciplinary research projects, some assumptions may be made here). In their study on researchers who move into the space left behind by deceased star-scientists, Azoulay et al. (2019) find a positive effect on citations received, which they explain with these scientists taking the role of leaders to steer a whole field in a new direction and break with existing paradigms, which were previously upheld by the now deceased star scientists. On the other hand, Borjas and Doran (2012, 2015a) find negative effects of the necessity-driven thematic mobility of U.S. mathematicians on their productivity as well as their likelihood to remain in science after the influx of Soviet scientists.

A comparison of existing studies on thematic mobility thus suggests that when looking at the effects of researchers' thematic mobility, one has to take into account the reasons for it. It is also important to look at the actual degree of mobility. When looking at interdisciplinary research projects, one has to ask whether the individual researcher is actually thematically mobile, or if the actual collaboration with scientists from a different field and the resulting knowledge exchange is held to a minimum. Ideally, one should also see whether the thematic mobility is towards an already existing field, or whether it breaks the existing boundaries and starts something completely new, not only to the researcher, but to the whole scientific community.

Chapter 2

Is Entrepreneurial Behavior Rewarded in Academia? Evidence from Post-Reunification Germany

2.1 Introduction

Academic entrepreneurship has become a key element of universities' strategies to transfer knowledge and technologies to the private sector (Rothaermel et al., 2007). Facilities to support faculty (Czarnitzki et al., 2016) and student (Åstebro et al., 2012; Buenstorf et al., 2017) entrepreneurs have been established on campuses around the globe, often with substantial help of public policy makers intent on boosting regional and national economic performance by increasing the number of academic startups. Beyond the encouragement of academic startups, universities increasingly like to see themselves

This chapter is based on joint work with Guido Buenstorf.

as entrepreneurial organizations. For instance, a leading German technical university not only refers to itself as “the entrepreneurial university” but in its mission statement encourages “an entrepreneurial spirit in all aspects of university life”. To “[t]hink and act like an entrepreneur” is codified as one of the eight principles included in the mission statement (Technical University of Munich (TUM), 2018).

As this example illustrates, university leaders have come to expect faculty and staff to be entrepreneurial in their attitudes and behavior. This is consistent with a broad notion of academic entrepreneurship (Franzoni and Lissoni, 2012) that highlights the importance of proactive behavior, discovery pursuit of opportunities, and organization-building activities as integral parts of successful careers in academia. But are faculty members rewarded if – as scientists[1] – they engage in behavior that can be characterized as entrepreneurial, i.e. if they venture outside the established boundaries of established disciplines, universities and activities and if they pursue highly uncertain career opportunities in uncharted institutional territory? This question is difficult to answer empirically. First, if new departments and research centers are opened, they are often built around star scientists whom the respective organization attempts to attract. Researchers also engage in active lobbying for new facilities. Accordingly, the opening of new facilities can often not be treated as exogenous. Second, many new departments and centers are part of existing organizations (e.g., branch campuses) and/or located in regions with well-established research infrastructure and pre-existing networks. Individual decisions to join the new facility may then reflect pre-existing ties that may be unobservable to the outside observer. Third, it is often difficult to disentangle genuinely entrepreneurial behavior from symbolic compliance with expectations that are imposed on the researcher by their university leadership and/or the broader public (Bercovitz and Feldman, 2008).

In this paper, we use the post-reunification restructuring of universities in Eastern Germany after 1990 as an empirical context to study the outcomes of entrepreneurial behavior in research. Following four decades of political interference and increasing isolation from international collaboration (at least outside the Eastern bloc), in 1990 the East German university system was generally seen as tainted by Marxist-Leninist ideology and lacking international competitiveness. As university research was

[1] In what follows, „scientist“ will be used as a catch-all term generally denoting university researchers in science, engineering, social science and the humanities.

considered crucial for the future of Eastern Germany, the subsequent process of radical restructuring was backed by large amounts of public funds. Germany's federalist political system moreover mandated that the Eastern university system become comparable to that in the West. As part of the restructuring process, the vast majority of professors were dismissed, relegated to second-tier positions or retired early. Their successors were mostly hired from Western Germany. The post-reunification academic labor market therefore offered substantial opportunities for those willing to venture East and join universities that were undergoing drastic organizational change and which were part of a research environment characterize by turmoil and "torn networks" (Albach, 1993).

We argue that taking faculty positions in post-reunification Eastern Germany can be interpreted as entrepreneurial behavior. Our analysis focuses on junior researchers in economics, business administration (*Betriebswirtschaftslehre*) and physics who were trained in the West and who were on the labor market for first-time faculty positions in the post-reunification period. We show that at the time of hiring, junior researchers who went East were no less productive, and in physics even more productive, than their peers hired at Western universities. However, we find no evidence that their move to the East paid off in terms of their subsequent research productivity. This suggests that the German university system did not reward their entrepreneurial behavior – a finding that in our view raises questions about the ability of the same system to motivate researchers to show the entrepreneurial spirit required to generate a powerful stream of academic startups.

Our paper adds to a long line of prior work that exploited the natural experiment of post-reunification Germany (e.g., Alesina and Fuchs-Schündeln, 2007; Burchardi and Hassan, 2013; Dorner et al., 2016). This study is also related to the small literature that investigates the effects of supply shocks to academic labor markets (Borjas and Doran, 2012; Waldinger, 2012, 2016), even though we study the reaction to an exogenous shock in demand for university scientists.

The remainder of this paper is structured as follows. In Section 2.2, we draw on the entrepreneurship literature to develop some ideas about how (West) German scientists would be expected to react to the opportunity shock brought about by reunification and the transformation of the Eastern universities.

Section 2.3 discusses the empirical context and the data used in our analysis. Section 2.4 presents and Section 2.5 discusses our results.

2.2 Entrepreneurial Behavior in Academia

2.2.1 Defining Entrepreneurship

Ever since Schumpeter (1911), entrepreneurship has been related to innovation. Knight (1922) added the element of enduring genuine uncertainty to the entrepreneurship concept, whereas Kirzner (1973) drew attention to entrepreneurs' ability to recognize opportunities as well as their willingness to act upon this recognition. Present-day entrepreneurship researchers likewise tend to adhere to an entrepreneurship concept that goes beyond the mere act of starting a new firm. For instance, drawing on Venkataraman (1997), Shane (2003, p. 4) defines entrepreneurship as an "activity that involves the discovery, evaluation and exploitation of opportunities to introduce new goods and services, ways of organizing, markets, processes and raw materials through organizing efforts that previously had not existed." Opportunities may be exploited within existing organizations – which is often referred to as "intrapreneurship" – and they need not be limited to profit-making opportunities (e.g., in social entrepreneurship; cf. Haugh, 2006).

Whether and how an opportunity is acted upon depends on characteristics of both opportunities and individuals, as well as the match between them. It has been shown that even if opportunities are held constant, individuals react rather differently to these opportunities (Shane, 2000). Exploitation of opportunities cannot be taken for granted; how opportunities are exploited is shaped by innate personality as well as training and prior experience. Survey evidence routinely shows that personality factors help predict entrepreneurial outcomes (cf., e.g., Parker, 2009, for a review of the evidence). At the same time, formal education affects both entrepreneurs' competence and their ability to signal these competences to stakeholders (cf. Buenstorf et al., 2017, and the literature discussed therein), and a substantial literature indicates that entrepreneurs are affected by their prior professional experience. Prospective entrepreneurs acquire various kinds of useful knowledge during their employment in existing organizations, including knowledge about technologies and markets (Christensen, 1993; Agarwal et al., 2004), knowledge about organizational processes and routines (Nelson and Winter, 1982) as well as personal skills and attitudes (Higgins, 2005) based on learning from others and from own experience. In a number of contexts a direct relationship between the performance of entrepreneurial firms and the performance of their founders' prior employers has been found (Helfat and Lieberman, 2002; Klepper and Sleeper, 2005; Buenstorf and Klepper, 2009), suggesting that incumbent firms are involuntary training grounds for prospective entrepreneurs.

2.2.2 Academic Entrepreneurship and Entrepreneurial Scientists

Are scientists entrepreneurial? Considering the overall number of academic startups, skepticism appears to be warranted. For instance, survey data for the U.S. indicates that only 1-2 per cent of all STEM faculty start firms (Åstebro et al., 2012). Numbers in other countries appear to be similar, even though numbers differ substantially depending on how exactly academic startups are defined.

As noted above, a more encompassing definition of academic entrepreneurship can be given. According to Franzoni and Lissoni (2012), "[a]cademic entrepreneurs are scientists with a brilliant scientific record, who build their careers through discipline-building, the creation and of new labs and teams, and an appetite for the economic resources necessary to pursue those goals." This suggests that the focus on academic entrepreneurship more narrowly construed – in the sense of scientists starting firms and commercializing the results of their research, i.e. participating in the university's "third mission" – is more of an extension than a radical shift in what successful scientists are expected to do.

Indeed there seem to be parallels between the requirements for success in science and in starting new ventures. Successful scientists are innovative in the questions they ask and the methods they use to answer these questions. They are alert to opportunities and willing to exploit them in spite of considerable uncertainty about outcomes. Following a prolonged period of on-the-job training, scientists direct research groups and laboratories of varying size, and need to acquire human as well as physical resources (Stephan, 2012) to keep these "firms" running. Scientific work tends to be collaborative in nature, thus scientists' own success is strongly dependent on the quality of their hiring decisions, on their ability to manage the group of researchers they employ in their group or laboratory, and also on their ability to raise sufficient funds to keep their research venture afloat. The relevance of entrepreneurial behavior in academia extends beyond the research group and laboratory. Successful scientists start new fields of inquiry, they organize scientific communities of varying size, edit journals, take positions in professional organizations etc. In all these activities scientists tend to enjoy significantly more autonomy than the average employee in other sectors. And again not dissimilar to entrepreneurs, the majority of university scientists forego personal income for autonomy (Åstebro et al., 2014) – by accepting lower salaries than comparable jobs in industry would provide, they "pay to be scientists" (Stern, 2004; Sauermann and Roach, 2014).

However, not all scientists conform equally well to the ideal of being entrepreneurial. Individual-level performance indicators in science are just as skewed as innovation indicators, suggesting that most scientists contribute little of lasting value to the scientific endeavor, whereas life-cycle patterns in individual research productivity (Levin and Stephan, 1991) are consistent with an exploration-exploitation sequence in scientists' activities. This raises the possibility that real-world scientists are not so entrepreneurial after all, and that the idea of entrepreneurship in academia is more of an idealist illusion or self-serving wishful thinking than a useful way to think about what scientists actually do. It also raises the issue whether the university system incentivizes scientists to behave like entrepreneurs, as incentives can be expected to affect both self-selection into academic careers and activities of those who embark on these careers.

2.2.3 Are Scientists Incentivized to Show Entrepreneurial Behavior?

The job of scientists is to produce new knowledge. Innovation thus is at the core of being a scientist, and exactly reproducing earlier work is not a viable strategy in academia. However, there are obviously many different shades of novelty, and it is well-known that most research is "normal" in that is builds on existing theoretical and empirical work (rather than challenging it) and makes incremental rather than "radical" contributions to the overall body of scientific knowledge (Kuhn, 1962). There may be good reasons for individual scientists not to venture too far from the established mainstream.

Substantial evidence suggests that scientific communities can be rather conservative and that highly entrepreneurial scientists face similar opposition to their ideas as Schumpeter (1911) described for innovative entrepreneurs. Such tendencies may be further pronounced by increasingly formalized assessment of researchers' achievements (Wang et al., 2017) and demands that research yield immediate "impact" (Salter et al., 2017).

Scientists' willingness to exploit career opportunities, and their individual success, moreover reflects their training and professional experience (Bercovitz and Feldman, 2008). Prior research finds evidence for scientists' individual behavior being affected by fellow students, co-workers (Krabel, 2012; Tartari et al., 2014; Hottenrott and Lawson, 2017) and doctoral advisors (Buenstorf and Geissler, 2014; Furman and Heinisch, 2019). In addition, present-day scientists are employees of large organizations that tend to be increasingly centralized in decision making and in which the pursuit of organization-level objectives requires individual scientists to signal their "fit" to organizational strategies (Krücken and Meier, 2006). This may limit the (perceived) scope and rewards for pursuing a highly divergent research agenda. In many countries, the university system is primarily public, and scientists are unionized public-sector employees who benefit from the high level of job security that the state provides as employer. Even in private universities, the tenure system often buffers senior researchers from the risk of losing their jobs, and obtaining tenure is a key step in the career advancement of academics.

These characteristics of the context in which university researchers work, and the incentives that emerge from these characteristics, suggest that entrepreneurial behavior of scientists cannot be taken for granted. While becoming a "star" scientist may require radical innovation and the type of behavior captured by the definition of (Franzoni and Lissoni, 2012), even the broad concept of academic entrepreneurship might then characterize only a minority of scientists because it requires risky strategies that are on average not rewarded by the researchers' environment. Given the incentives they face in the university system, it may primarily be the less entrepreneurial types who self-select into academic careers. In addition, one might also argue that the mere fact of remaining in the familiar environment of the university system upon graduation – instead of migrating to another, less well-known employment context – may already indicate that scientists are not particularly entrepreneurial.

2.3 Empirical Context

2.3.1 The German Academic Labor Market

In most countries academic labor markets are relatively structured regarding the requirements for specific positions and the sequences of individual careers. Similar to other countries, the doctoral degree is the first step toward an academic career in Germany. However, to an even greater degree than for example in the U.S. (Stephan et al., 2005), graduates from doctoral programs leave academia and pursue careers in the private sector. Fortunately for our empirical design, the doctoral degree has traditionally not been sufficient to be hired into faculty positions at German universities, and a tenure-track system has only been introduced after the time period we study.[2] Instead, young scientists aspiring to become professors had to complete another career stage, the *Habilitation*, which is best thought of as a second doctoral degree. The core of the *Habilitation*, which gives a person the right to teach at a university and has thus for a long time been a quasi-prerequisite for receiving tenure, was to write and defend another dissertation (traditionally taking the form of a monograph).

Completing the *Habilitation* was a necessary condition to enter the labor market for professorships. In contrast, according to conventional wisdom, the *Habilitation* has little if any value outside the academic labor market. While leaving academia after receiving a doctoral degree is common and usually offers rather high initial wages, the same cannot be said for the *Habilitation*.[3] And as the *Habilitation* typically requires five or more years and employers tend to prefer younger job candidates, starting (and completing) a *Habilitation* is a strong signal that an individual aspires to enter into an academic career. We accordingly take individuals who completed their *Habilitation* as our basic units of observation.

For our sample of individuals with completed *Habilitation*, success is easy to define as the first faculty position attained. Faculty positions in Germany are comparatively rare. They come with

[2]Only after the turn of the century has the *Habilitation* lost some of its importance in Germany, with the number of *Habilitationen* having peaked in 2002 (Statistisches Bundesamt, 2015). This is due to a shift in policy and the introduction of alternative career paths such as the Juniorprofessur or tenure track systems. Nevertheless, the *Habilitation* still is an important career step in certain academic fields in Germany.

[3]Little systematic evidence exists to verify this view.

tenure and are often attained only at about age 40. Accordingly, careers of junior scientists are characterized by high levels of uncertainty (Schulze et al., 2008).

A small number of prior studies has used this characteristic of the German academic labor market to construct a risk set of young researchers looking for tenure by collecting data on researchers who received a *Habilitation* (Schulze et al., 2008; Jungbauer-Gans and Gross, 2013). This approach allows to avoid problems of survivor bias encountered by studies that only sample individuals active in academia.

2.3.2 German Reunification and the Labor Market for Junior Scientists

In November 1989 the Berlin Wall was opened and East German citizens were able to move freely. In March 1990 a democratic government was elected in East Germany, and in October 1990 Germany was reunified after more than 40 years of division. For the East German society reunification meant a drastic and all-encompassing shock. With very few exceptions, laws and regulations were taken over from West Germany. Wages and salaries quickly increased, which meant that the Eastern manufacturing sector lost whatever competitiveness it might have possessed otherwise. Mass unemployment entailed, and it was only because of immense transfer payments from the West that mass poverty (as experienced in many other transition countries) could be avoided.

Similar to other societal spheres, the East German university system was completed restructured and adapted to the Western model. Even though most East German universities had been established long before World War 2 and the subsequent division of Germany, after 40 years of socialism they differed from their Western counterparts in numerous ways. Most importantly, science and higher education had been shaped along ideological lines, and the strong hand of the communist party had left its traces throughout the system. Open exchange of knowledge with the West was essentially impossible for most researchers in the East, as they often could not even access Western journals (Günther and Schmerbach, 2010). Curricula and research agendas reflected party prerogatives, particularly in the social sciences and humanities where Marxist-Leninist ideology reigned, but also in science and engineering departments, which had been turned into research service providers catering to the needs of state-owned firms. In addition, following the example of the Soviet Union, socialist East Germany had given up the Humboldtian ideal of unity of research and higher education in favor of research activities being concentrated outside the university system in the institutes of the *Akademie der Wissenschaften.*

All this changed rapidly after 1990. Marxist-Leninist social science departments and the *Akademie der Wissenschaften* were dismantled. Established scientists from the West assumed interim leadership positions at the Eastern universities and their departments, rebuilding these organizations after the Western model and with scientists mostly hired from the West. All Eastern scientists had to pass a thorough review of their research performance and their entanglement in the socialist regime. Here they faced a dilemma: Interaction with Western scientists and travel opportunities had been extremely restricted. At most, some top scientists who were moreover deemed politically reliable might have been permitted to travel abroad and keep abreast of the most recent developments outside the socialist world. However, the required closeness to the ruling party for those in leadership positions tended to decrease an individual's chances to keep their academic job after reunification.

The need to replace the vast majority of scientists at Eastern universities induced a significant demand shock in the years following reunification. Young researchers from West Germany who had completed their *Habilitation* or were on their way to do so were the main beneficiaries (Schulze et al., 2008). In addition to the Western university, there was now a set of new potential employers that hired substantial numbers of new faculty.

For the junior researchers at the center of our study, reunification created a substantial number of job openings for which they were perfectly qualified. Regarding formal requirements and working conditions, as well as income, faculty positions at Eastern universities were not fundamentally different from those in the West. Entry-level salaries for university professors differ little across *Bundesländer* (who are responsible for higher education) or individual universities. Entering an Eastern department promised some advantages over accepting a position at a Western university. First, it meant to enter an organization that was restructuring and hiring, which opened up opportunities for shaping the future development of the university and the department. Early hires at Eastern departments could subsequently influence the hiring of their peers, which provided them with rich opportunities to establish clusters of scientists with similar research interests. In addition, particularly in the first post-reunification years students-faculty ratios were much smaller than in the West, which added to the attractiveness of Eastern universities. And while the quality of university facilities and the built infrastructure tended to be poor at first, it was obvious from the beginning that huge amounts of funds would be spent on improving them. If scientists moved East, they often found relatively inexpensive housing, but also lack of amenities and a substantial degree of cultural differences between East and West – both in their private life but also in the interaction with university administrations that were primarily staffed with Eastern employees.

Regarding East-West differences in academic quality and reputation, it is difficult to make uniform statements. Some Eastern universities looked back on a strong pre-war tradition and/or aspired to become a leading university again (e.g., Humboldt University Berlin or the University of Jena). At the same time, differences in academic quality and reputation were non-negligible among Western universities, a substantial number of which had been established in the 1970s and which all had experienced drastic increases in the number of students over the previous decades.

Both the system-level effects of the post-reunification demand shock in the academic labor market and the individual-level repercussions on the careers of junior researchers joining Eastern universities have not been explored in detail before. In our subsequent analysis, we draw on prior work has shown the relevance of supply and demand conditions for career outcomes. Entering the labor market during times of low demand tends to reduce the quality of initial placements and, as a result, long-term career outcomes. Such cohort effects have been found both for the private sector and for academic labor markets. In the private sector, they primarily show in lower long-term wages and lower chances of getting highly desired jobs, (Oyer, 2008; Kahn, 2010; Oreopoulos et al., 2012). In academia they primarily mean lower chances of receiving jobs at highly ranked institutions, and also long-term negative effects on the count and quality of publications (Oyer, 2006; Stephan, 2012).

While there is little prior work on demand shocks to academic labor markets, several prior studies analyze the effects of supply-side shocks. Borjas and Doran (2012) study the impact of Soviet immigration on U.S. mathematics, finding that immigrants outcompeted U.S.-trained mathematicians, whereas there is little evidence of knowledge spillovers. Moser et al. (2014) similarly study the role of Jewish emigrés in U.S. chemistry patenting, finding substantial productivity and spillover effects (through inducing new entry into affected fields). Waldinger's work (2012; 2016) shows how devastating and long-lasting the effects of the Nazi dismissals of Jewish and opposition researchers were for German academia.

2.3.3 Dataset

To study the effects of the post-reunification demand shock on junior (and mostly Western) German scientists, we constructed a unique dataset that covers young researchers who received their *Habilitation* at West German universities between 1981 and 2000, and at East German universities between 1991 and 2000, in the disciplines of physics, economics and business studies. Individuals who completed their *Habilitation* at Eastern universities after 1990 include East Germans who were young enough to complete their education according to Western standards, but also Westeners who went East at earlier stages of their education (e.g., for doctoral training).

As information about *Habilitation* degrees is not collected centrally in Germany, we combined different sources. First, we use data from the German National Library (*Deutsche Nationalbibliothek* or DNB), which collects data on all German publications and makes them available in an online catalog. As opposed to doctoral dissertations (Buenstorf and Geissler, 2014), the information on *Habilitationen* in the DNB catalog is incomplete, and there are moreover systematic biases in the coverage of individual universities and disciplines. We therefore added data about completed *Habilitationen* published in the *Deutsche Universitätszeitung* (duz), a bi-monthly magazine for and about universities and science, and also contacted the deans' offices of our focal disciplines at all German universities to obtain further information. Using all these sources, we ended up with a list of 1,029 *Habilitationen* in physics and 665 *Habilitationen* in economics and business administration for the time between 1981 and 2000. In all three disciplines, this corresponds to about 70 percent of the numbers reported in official statistics. In contrast to the official statistics, our dataset contains researchers' names, the subject and year of *Habilitation* as well as the university that granted it.

For all scientists in this dataset we then searched for information about obtained professorships, again using information from duz for the years 1981 to 2010. We also matched the dataset to the 1996, 2007 and 2010 volumes of *Kürschners Deutscher Gelehrtenkalender*, a commercial register of German university professors with virtually complete coverage. For researchers listed as professors in *Kürschners*, information about when they were hired was obtained from online CVs and other sources. In order to provide further information about the scientists in our sample, we matched the dataset to DNB data on dissertations, which gave us information about location and year of the dissertation.

Publication data are used to measure the productivity of junior scientists and how it changes for those who are hired at Eastern and Western universities. We employ three different publication databases: Thomson Reuters Web of Science for publications in physics, Elsevier Scopus for economics and the German WiSo database for publications in business administration. The latter choice reflects that at in the time period we study, most business administration publications were written in German and are not included in the other databases. Given limited personal information in our data, publications were mostly matched based on names and disciplines. Because of data limitations and homonym problems, the final sample was reduced to 849 physicists, 311 economists and 280 business economists.

2.4 Econometric Analysis

2.4.1 German Reunification as an Opportunity Shock for Scientists

We begin our empirical analysis by tracing the nature and extent of changes in the academic labor market brought about by reunification. Specifically, we analyze the hazard rate of obtaining a professorship at a German university using complementary log-log regression models with a polynomial specification of the baseline hazard (denoted by the variables *spell year* and *spell year squared*). This allows us to assume a non-linear baseline hazard, which can be expected because, while the probability of obtaining a professorship may well increase in the first years after the *Habilitation*, it probably starts going down at some point in time. Subjects enter the risk pool at the time of their *Habilitation* and exit at the time they are hired. Censoring occurs if a subject becomes an adjunct professor or is hired outside of Germany.

We divided our sample into four 5-year *Habilitation* cohorts, with the first (1981-1985) and the last (1996-2000) of the cohorts being far away from reunification in 1990 so that their hiring probabilities should not be affected by reunification, and the intermediate ones (1986-1990 and 1991-1995) being more likely to be affected. The cohort dummies accordingly are our measure of how sizeable the opportunity shock was in the various disciplines.

In addition to labor market conditions, we expect individual chances to obtain a professorship to be dependent on research productivity. Given disciplinary differences in publication activities and the reward structure for publication output, different productivity measures are used for physics, economics and business studies. (We hasten to add that all these measures suffer from the general limitations of quantitative indicators of research productivity.) For researchers in physics, we measure productivity by counting the total number of citations for their five top-cited papers. This should be a reasonable measure since the number of publications per researcher is generally high in physics, with the number of citations differing strongly and large numbers of citations being rare. In economics, we use the stock of papers an individual researcher has published to measure their productivity, using publication data from Scopus. We do the same for business administration using WiSo publication data. As a second proxy of research performance we use *time diss-habil*. This variable measures the number of years between dissertation and *Habilitation*.

A gender dummy taking the value 1 if a researcher is female is included in all models. We also include a dummy that takes the value 1 if the university at which the researcher received their *Habilitation* was founded after 1960. We do so because “Traditionsuniversitäten” founded before 1960 (including universities such as Heidelberg and Göttingen) generally have better institutional reputation than the new ones founded during the expansion of the West German higher education systems starting in the 1960s. We also control for *Habilitationen* received at Eastern universities (after 1990) because similar issues of lacking institutional reputation could be expected here. Third, we control for affiliation

Table 2.1: Descriptive Statistics

total number (percentage in brackets)	physics	economics	business administration
Habilitationen	849	311	280
professorships	269 (31.7)	164 (52.7)	227 (81.1)
female	39 (4.6)	31 (10.0)	22 (7.9)
average number (std. dev. in brackets)			
publication stock 2010		4.6 (8.5)	40.9 (41.3)
top5 citations 2010	320.9 (425.5)		
time diss-habil	9.1 (3.9)	8.1 (3.9)	7.0 (3.2)

Note: Descriptive statistics comparing physicists, economists and business administration researchers. Averages are arithmetic means.

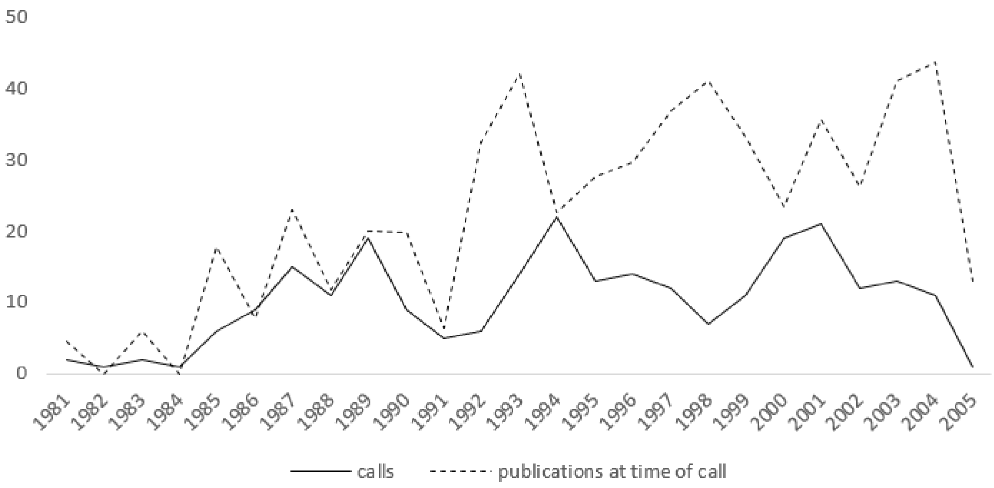
changes between dissertation and *Habilitation* that may decrease a researcher's short-term productivity (Bäker, 2015). Descriptive statistics for the main variables are shown in Table 2.1.

The extent to which the post-reunification opportunity shock differed across disciplines can be seen in Figure 2.1, which shows both the number of open professorships per year and the mean number of publications of successful candidates in the respective year (which increases in all disciplines even though levels – due to the different measures employed – differ strongly across disciplines). A post-reunification increase in the number of open positions can be seen in all three disciplines, but it is least pronounced in business administration. These patterns are consistent with results of the complementary log-log hazard rate analyses (separately estimated for the three disciplines) that are reported in Table 2.2. They indicate that German reunification resulted in an opportunity shock in all three disciplines. While in business administration, this shock seems less pronounced and can only be shown for the post-reunification *Habilitation*-cohort, in both physics and economics, members of the cohorts of scientists who had completed their *Habilitation* right before or right after German reunification have higher odds of obtaining professorships than those in the first cohort (and the last one, which is the omitted reference group).

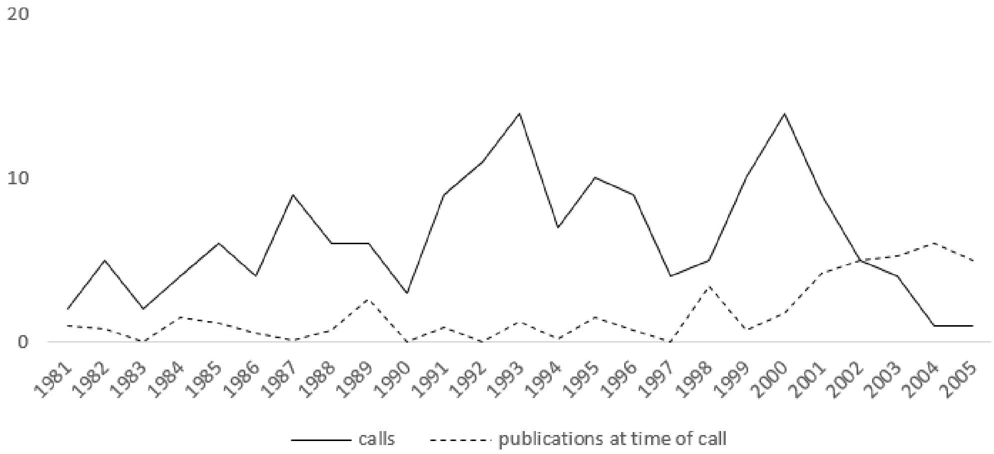
To some extent, this pattern comes as a surprise, since the opportunity shock might have been expected to be greater in the social sciences where the post-reunification restructuring of the Eastern departments was more radical than in the sciences. A possible explanation is provided by the high hiring rates in business administration. Only 53 of the 280 researchers in business administration in our sample (less than 20 percent) never obtain a professorship in Germany. Presumably reflecting good opportunities in the non-academic labor market (and possibly a more traditional model of mentoring and support for post-doctoral researchers known as the "Generationenvertrag" where professors make extensive use of their own networks to secure jobs for their students), the extent of the opportunity shock in business administration was limited.

The estimates for the baseline hazard through the variables *spell year* and *spell year squared* show that both in physics and economics, the baseline hazard has the expected inverted U-shape, with the risk of being hired increasing in the years after the *Habilitation*, reaching its peak around the four- or five-year mark, and starting to decrease afterwards. No such shape can be found in business administration, where the overall chance of being hired is much higher than in the other two disciplines, and the average time from *Habilitation* to hiring is lowest.

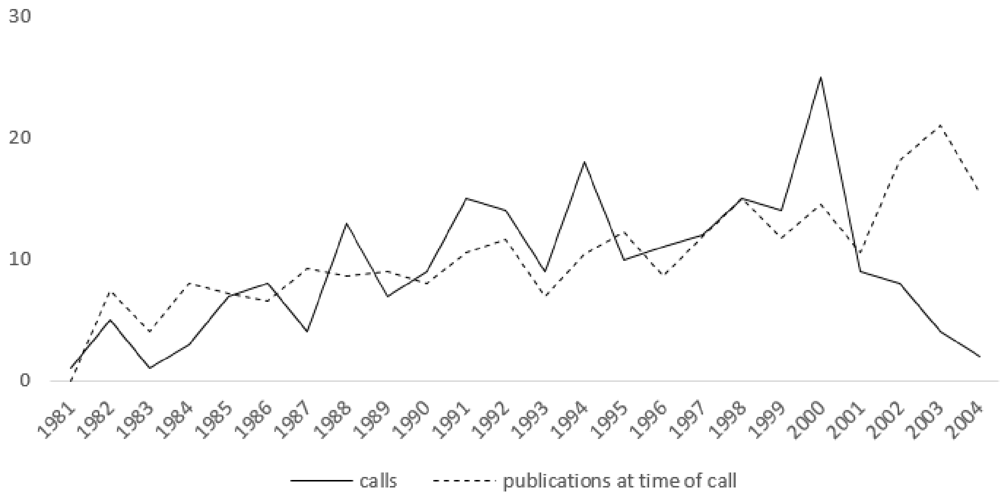
We moreover find young researchers' productivity to have a significant effect on the chances of obtaining a professorship. The time needed for the *Habilitation*, as a different proxy of productivity, has the expected effect on the chances of becoming a professor in all observed disciplines. We find no effect of a change of affiliation between dissertation and *Habilitation* that cannot be explained through productivity. The gender dummy is only significant in physics, indicating better hiring chances of female scientists. Note, however, that in the 1980s and 1990s the numbers of women completing a *Habilitation* was very small in all three disciplines.



(a) Physics



(b) Economics



(c) Business Administration

Figure 2.1: Number of calls received and number of publications at time of call

Table 2.2: Hazard of obtaining a professorship

	Failure:		
	Call received		
	model 1 (physics)	model 2 (economics)	model 3 (business admin.)
cohort 1	0.078	0.114	0.057
(1981-1985)	(0.187)	(0.232)	(0.206)
cohort 2	0.591***	0.609***	0.176
(1986-1990)	(0.177)	(0.227)	(0.199)
cohort 3	0.326*	0.995***	0.392**
(1991-1995)	(0.167)	(0.231)	(0.174)
publication stock		0.133***	0.018***
		(0.025)	(0.006)
top5 citations	0.001***		
	(0.000)		
female	0.793***	−0.069	−0.020
	(0.252)	(0.288)	(0.284)
habil east Germany	−0.366	−0.386	−0.260
	(0.229)	(0.431)	(0.371)
uni founded after	−0.034	0.116	0.089
1960	(0.156)	(0.183)	(0.163)
uni change	0.060	0.089	0.210
	(0.130)	(0.174)	(0.156)
time diss-habil	−0.086***	−0.109***	−0.070***
	(0.020)	(0.026)	(0.024)
spell year	0.362***	0.278***	−0.116
	(0.0071)	(0.102)	(0.083)
spell year squared	−0.036***	−0.038***	−0.011
	(0.006)	(0.009)	(0.008)
constant	−3.506***	−2.272***	−0.727***
	(0.275)	(0.319)	(0.238)
N(failures)	849(269)	311(164)	280(227)
observations	9,607	2,669	1,214
LR chi2	265.26	197.05	155.00
p>chi2	0	0	0

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from complementary log-log regression models. Standard errors in parentheses.

2.4.2 Who Went East?

We now turn to the question which of the researchers in our sample obtained their first faculty position at one of the universities in the transforming Eastern part of Germany. To address this question, we estimate standard multinomial logit models distinguishing between hires in the East and in the West (not obtaining a professorship is the omitted reference category). Results of these models are reported in Tables 2.3-2.6. We estimate these models for the full sample as well as for the individual disciplines. In addition to using the full sample of young researchers, we also restrict the sample to those who had completed their *Habilitation* by 1990, omitting cohorts 3 and 4 in the "early" model variants.

Our results indicate that obtaining a professorship in either part of the country is predicted by research productivity in terms of publication output. For this and all following analyses we use a uniform publication measure based on journal publications for all disciplines. Publications are counted at the time of being hired or three years after the *Habilitation*. (Using publication measures at the time of *Habilitation* generates similar results.) A (marginally) significant difference between Eastern and Western hires is only obtained for the early physicists; it suggests that more productive scientists tended to go East. Researchers who needed longer to complete their *Habilitation* were less likely to obtain a professorship. In the early cohorts, it was predominantly those who completed their *Habilitation* relatively briefly before reunification who were hired in the East, which is another indication that reunification resulted in a relevant opportunity shock for these researchers.

Comparing across disciplines, hiring chances were better in economics and business administration than in physics. We moreover find that hires to the East disproportionately came from non-traditional universities. This pattern is driven by physics and limited to the later cohorts. Among the early cohort, and apparently driven by the physicists and business administration researchers in the sample, those who had switched universities for the post-doc phase are more likely to go East. This might indicate their more entrepreneurial attitude, but also a lack of support in their home institution. Note also that in the early cohorts, university changers in business administration are strongly punished at Western universities.

Table 2.3: Characteristics of researchers obtaining professorships at Eastern and Western universities (all disciplines)

	All			*All early*		
	call west	call east	difference	call west	call east	difference
publication stock	0.022***	0.024***	0.002	0.025***	0.039***	0.014
at first call	(0.003)	(0.005)	(0.005)	(0.006)	(0.011)	(0.009)
year habil	−0.050***	0.027	0.077***	0.060*	0.594***	0.533***
	(0.010)	(0.021)	(0.021)	(0.033)	(0.138)	(0.136)
female	0.246	0.127	−0.119	0.373	−12.802	−13.175
	(0.253)	(0.432)	(0.415)	(0.588)	(721.488)	(721.488)
university type						
(ref.: trad.)						
young	0.028	0.503	0.474	0.210	0.164	−0.046
	(0.163)	(0.304)	(0.289)	(0.260)	(0.731)	(0.711)
east	−0.582**	0.838**	1.420***			
	(0.253)	(0.393)	(0.397)			
TU9	−0.171	0.496*	0.667**	−0.240	0.505	0.744
	(0.150)	(0.297)	(0.288)	(0.215)	(0.601)	(0.590)
field						
(ref.: physics)						
economics	0.997***	1.548***	0.551*	0.774***	1.963***	1.190*
	(0.159)	(0.332)	(0.330)	(0.227)	(0.662)	(0.650)
business admin.	2.096***	2.761***	0.665**	2.417***	2.091**	−0.326
	(0.200)	(0.322)	(0.291)	(0.394)	(0.934)	(0.864)
uni change	0.147	−0.344	−0.491**	0.200	1.140**	0.940*
	(0.127)	(0.255)	(0.249)	(0.204)	(0.570)	(0.556)
time diss-habil	−0.084***	−0.087**	−0.004	−0.096***	−0.166**	−0.070
	(0.017)	(0.035)	(0.035)	(0.027)	(0.074)	(0.072)
constant	99.378***	−56.747	−156.125***	−119.690*	−1183.112***	−1063.422***
	(20.842)	(42.725)	(41.380)	(66.291)	(273.740)	(270.521)
observations		1,440			602	
LR chi2		317.71			136.65	
p>chi2		0			0	
log-likelihood		−1128.266			−409.118	

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from multinomial logit models, standard errors in parentheses. Reference category is those who did not obtain a professorship. Publication stock at first call is set to publication stock three years after *Habilitation* if no call received.

Table 2.4: Characteristics of researchers obtaining professorships at Eastern and Western universities (physics only)

	Physics			*Physics early*		
	call west	call east	difference	call west	call east	difference
publication stock	0.022***	0.027***	0.005	0.025***	0.043***	0.018*
at first call	(0.003)	(0.006)	(0.005)	(0.006)	(0.012)	(0.011)
year habil	−0.054***	−0.018	0.037***	0.042	0.663***	0.621***
	(0.013)	(0.034)	(0.034)	(0.040)	(0.234)	(0.233)
female	0.879**	0.935	0.057	−0.359	−9.670	−9.311
	(0.362)	(0.693)	(0.696)	(0.962)	(595.674)	(595.674)
university type (ref.: trad.)						
young	−0.015	1.671***	1.686***	−0.231	1.020	1.251
	(0.214)	(0.641)	(0.644)	(0.328)	(0.946)	(0.937)
east	−0.607**	1.932***	2.533***			
	(0.296)	(0.661)	(0.676)			
TU9	0.023	1.598***	1.575***	0.033	0.719	0.686
	(0.178)	(0.583)	(0.583)	(0.251)	(0.918)	(0.907)
uni change	0.123	−0.456	−0.580	0.280	1.544*	1.264
	(0.156)	(0.383)	(0.386)	(0.244)	(0.812)	(0.802)
time diss-habil	−0.082***	−0.084	−0.002	−0.102***	−0.144	−0.042
	(0.021)	(0.052)	(0.052)	(0.034)	(0.101)	(0.099)
constant	108.202***	31.371	−76.831	−83.777	−1322.033***	−1238.256***
	(26.367)	(67.784)	(67.930)	(79.715)	(466.122)	(463.951)
observations		849			363	
LR chi2		118.64			57.05	
p>chi2		0			0	
log-likelihood		−643.256			−258.921	

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from multinomial logit models, standard errors in parentheses. Reference category is those who did not obtain a professorship. Publication stock at first call is set to publication stock three years after *Habilitation* if no call received.

Table 2.5: Characteristics of researchers obtaining professorships at Eastern and Western universities (economics only)

	Economics			*Economics early*		
	call west	call east	difference	call west	call east	difference
publication stock	0.325***	0.316**	−0.009	0.041	0.054	0.014
at first call	(0.101)	(0.122)	(0.910)	(0.132)	(0.230)	(0.213)
year habil	−0.032	0.034	0.067*	0.144**	0.662***	0.517**
	(0.021)	(0.040)	(0.039)	(0.073)	(0.224)	(0.219)
female	0.026	−0.965	−0.991	1.010	−13.904	−14.914
	(0.414)	(1.085)	(1.082)	(0.895)	(1785.07)	(1785.069)
university type						
(ref.: trad.)						
young	0.352	−0.111	−0.462	0.950*	−13.698	−14.648
	(0.319)	(0.634)	(0.608)	(0.554)	(1025.888)	(1025.887)
east	−1.099	0.431	1.529			
	(0.736)	(1.011)	(1.029)			
TU9	−0.542	−0.113	0.428	−1.053**	−0.405	0.648
	(0.360)	(0.635)	(0.628)	(0.484)	(1.012)	(0.995)
uni change	0.298	−0.759	−1.058*	0.722	0.330	−0.392
	(0.285)	(0.631)	(0.616)	(0.477)	(1.276)	(1.229)
time diss-habil	−0.082**	−0.113	−0.031	−0.133**	−0.287*	−0.155
	(0.035)	(0.079)	(0.078)	(0.061)	(0.169)	(0.166)
constant	65.398	−68.654	−134.053*	−285.198**	−1314.29***	−1029.092**
	(42.391)	(79.972)	(77.720)	(144.668)	(444.653)	(434.428)
observations		311			149	
LR chi2		42.21			37.32	
p>chi2		0			0.001	
log-likelihood		−257.438			−103.895	

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from multinomial logit models, standard errors in parentheses. Reference category is those who did not obtain a professorship. Publication stock at first call is set to publication stock three years after *Habilitation* if no call received.

Table 2.6: Characteristics of researchers obtaining professorships at Eastern and Western universities (business admin. only)

	Business administration			*Business administration early*		
	call west	call east	difference	call west	call east	difference
publication stock	0.043	0.011	−0.032	−0.003	−0.023	−0.020
at first call	(0.026)	(0.032)	(0.024)	(0.057)	(0.135)	(0.127)
year habil	−0.124***	0.033	0.156***	0.032	0.573	0.541
	(0.040)	(0.053)	(0.042)	(0.153)	(0.515)	(0.500)
female	−0.947	−0.840	0.107	−0.916	−1.656	−0.740
	(0.591)	(0.740)	(0.644)	(7773.139)	(17331.94)	(15491.11)
university type (ref.: trad.)						
young	−0.644	−0.015	0.629	15.854	0.552	−15.302
	(0.472)	(0.570)	(0.436)	(1547.914)	(3204.34)	(2805.665)
east	0.303	0.521	0.219			
	(1.190)	(1.331)	(0.899)			
TU9	−1.454***	−0.820	0.633	−0.911	1.881	2.792
	(0.477)	(0.607)	(0.520)	(0.855)	(2.352)	(2.266)
uni change	0.058	0.118	0.060	−1.687**	0.074	1.761
	(0.441)	(0.546)	(0.429)	(0.837)	(1.730)	(1.615)
time diss-habil	−0.143**	−0.097	0.046	−0.008	0.112	0.120
	(0.056)	(0.075)	(0.066)	(0.113)	(0.212)	(0.193)
constant	249.506***	−64.084	−313.590***	−59.907	−1140.27	−1080.363
	(79.038)	(105.052)	(84.291)	(303.926)	(1023.552)	(994.838)
observations		280			90	
LR chi2		46.31			14.47	
p>chi2		0			0.416	
log-likelihood		−196.557			−29.166	

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from multinomial logit models, standard errors in parentheses. Reference category is those who did not obtain a professorship. Publication stock at first call is set to publication stock three years after *Habilitation* if no call received.

2.4.3 Research Performance in East and West

So far our analysis shows that junior researchers who accepted faculty positions at Eastern universities were comparable or possibly even superior to those who were hired at Western universities in the post-reunification years. This suggests that moving East was not driven by the lack of other options, but may really reflect an entrepreneurial attitude as was argued above. But did the move to the more malleable Eastern environment, which however was characterized by more uncertainty about how the individual department and university would further develop, actually pay off for the entrepreneurial junior researchers? To answer this question, we analyze hired individuals' publication outputs (both before and after being hired).

Table 2.7 shows the results of six poisson-pseudo-maximum-likelihood-models. The dependent variable in all six models is the number of publications in time period t. Models 1 and 2 include the whole sample, with a set of control variables and period-dummies (6 dummies denoting 5-year time periods between 1981 and 2010) added in model 2. Models 3-6 again take a closer look at the respective disciplines, with model 6 including both business and economics researchers. The dummy variable *after call* takes the value 1 if the observation is after the call of the researcher. In the simplified model, this variable has a significant positive effect. Including further controls and looking at the specific disciplines shows that this effect is driven by business administration researchers, who seem to publish more after being hired as a professor, and by the fact that publishing frequency increased over time, which can be seen by the effect disappearing in model 2, in which period effects are included. The variable *call east*, which takes the value 1 if the researcher's first appointment as a professor was to an east German university, has no effects at all. Neither does the interaction term of the two previously discussed variables, which takes the value 1 only if the observation is for a researcher who has already been hired at an east German university. This is our main variable of interest, and it shows that no "treatment effect" can be found for being hired in the east. The strongest predictors for publication output are again the disciplinary differences.

Finally, in Table 2.8 we look at another outcome variable for the young researchers in our sample who obtained professorships: the likelihood of leaving their first appointment and switching to another

Table 2.7: Publication counts of newly hired professors (hired between 1991 and 1995)

	Dependent variable: number of publications (in time period t)					
	model 1	model 2	model 3 (physics only)	model 4 (econ only)	model 5 (business only)	model 6 (econ & business)
after call	0.837***	−0.131	−0.268	−0.934	0.233*	0.438***
	(0.095)	(0.119)	(0.169)	(0.580)	(0.143)	(0.139)
call east	0.153	0.076	0.076	0.096	0.079	0.059
	(0.275)	(0.263)	(0.357)	(0.697)	(0.237)	(0.224)
after call∗call east	−0.170	−0.134	−0.061	−0.187	−0.276	−0.227
	(0.168)	(0.172)	(0.226)	(0.556)	(0.243)	(0.228)
field (ref.: physics)						
economics	−2.483***	−2.416***				
	(0.263)	(0.264)				
business administration	−0.522***	−0.346*				1.941***
	(0.179)	(0.208)				(0.257)
female		−0.288	−0.067		−0.386	−0.462
		(0.349)	(0.772)		(0.319)	(0.332)
year habil		−0.054	−0.072*	0.094*	−0.008	0.012
		(0.033)	(0.041)	(0.056)	(0.048)	(0.041)
constant	0.373**	107.054	143.399*	−191.661*	14.365	−27.954
	(0.168)	(65.953)	(81.791)	(112.387)	(94.732)	(81.842)
period effects included	No	Yes	Yes	Yes	Yes	Yes
regressors excluded to ensure estimates exist				female (60 obs. dropped)		
observations(individuals)	5,160(172)	5,160(172)	1,800(60)	1,380(46)	1,920(64)	3360(112)
R-squared	0.138	0.167	0.069	0.089	0.124	0.227
pseudo-log-likelihood	−10,467.7	−10,090.5	−5,646.8	−763.4	−3,513.6	−4,332.7

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Estimates from poisson-pseudo-maximum-likelihood models, robust clustered (on individual level) standard errors in parentheses. Period dummies are six dummies denoting 5-year time intervals from 1981 to 2010.

Table 2.8: Hazard of receiving and accepting a second call (for those hired between 1991 and 1995)

	Failure:			
	Second call received			
	model 1	model 2	model 3 (econ. only)	model 4 (econ. only)
first call east	−0.251	−0.061	−1.284**	−1.259**
	(0.775)	(0.781)	(0.570)	(0.598)
publication stock	−0.008	−0.007	0.095**	0.090**
	(0.007)	(0.007)	(0.039)	(0.041)
female	−0.446	−0.374	−0.255	−0.155
	(0.600)	(0.607)	(1.034)	(1.056)
field (ref.: physics)				
economics	1.108***	1.002**		
	(0.424)	(0.428)		
business administration	0.664*	0.488		
	(0.396)	(0.427)		
econ*first call east	−0.921	−1.051		
	(0.951)	(0.959)		
bus. ad.*first call east	0.553	0.499		
	(0.893)	(0.895)		
first call top uni		0.524		0.129
		(0.366)		(0.588)
time habil call		−0.082		0.018
		(0.069)		(0.086)
uni change		−0.266		−0.265
		(0.293)		(0.587)
duration dummies included	Yes	Yes	Yes	Yes
N(failures)	172(61)	172(61)	48(23)	48(23)
observations	1,872	1,872	348	348
Wald chi2	583.53	574.53	142.41	142.05
p>chi2	0	0	0	0

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from complementary log-log regression models. Standard errors in parentheses.

university. We estimate the hazard of changing jobs using another complementary log-log hazard framework, this time with fully non-parametric baseline hazards, and find that business scholars are twice as likely as physicists, and economists are more than three times as likely, to leave their first appointment.[4] However, no significant differences are obtained between those initially hired in the East and those hired in the West (models 1 and 2). Given substantial estimates of hazards, this is partially owed to low statistical power. Re-estimating the model for the economists only (models 3 and 4) – who are the most peripatetic group in the sample – we even find a substantially (more than 70 per cent) and statistically significantly lower hazard of switching jobs among those who started their professorial career at an Eastern university.

2.5 Discussion and Conclusions

Adopting a broad notion of academic entrepreneurship, we used the academic labor market in post-reunification Germany as a natural experiment, allowing us to study the rewards to entrepreneurial behavior in academia. Specifically, given the dynamic yet uncertain environment of post-reunification East German universities, we interpreted junior researchers who accepted their first faculty position in the East as academic entrepreneurs. Consistent with this interpretation, our analysis showed that, at the time of hiring, those who went East were at least as productive as those who were hired at Western universities. They often came from non-traditional Western universities and/or had already switched affiliations after completing their doctoral degree. Our quantitative analysis also indicated the presence of a post-reunification opportunity shock for entrepreneurial junior researchers, particularly in physics and economics but slightly less so in business administration.

In terms of post-hiring publication output, those who went East are indistinguishable from those who were hired in the West. Apparently, professorships in the restructuring Eastern universities did not enable the young researchers hired there to outperform their peers who worked in more established organizational contexts. This suggests that their willingness to exploit the opportunity to work in a

[4] As in Table 2.2, we decided to report coefficients instead of hazard ratios here.

dynamic yet uncertain environment was not rewarded by the university system. In other words: their entrepreneurial behavior did not pay off.

Numerous potential explanations can be provided for this finding. For example, the lack of more senior faculty who were experienced in the Western university system made it harder for the migrating junior scientists to thrive in the East. The task of building up their departments may also have absorbed them. It has not been the objective of this paper to identify the causes of the unspectacular post-hiring productivity of scientists who migrated to the East. However, it indicates the inability of the German university to reward them for their entrepreneurial behavior. If other forms and instances of academic entrepreneurship (broadly construed) face similar outcomes, then we can expect entrepreneurial individuals to self-select out of the university system and/or to learn to abstain from entrepreneurial behavior. This in turn would compromise the ability of universities to become truly entrepreneurial – both as regards the commercialization of university inventions through startups and licensing and as regards a proactive approach to the exploitation of opportunities in their other activities such as research and teaching.

Before we conclude, we want to point out limitations from which the above findings suffer. These limitations include that our sample of researchers who completed their *Habilitation* is representative but nonetheless incomplete. We also lack information about young scientists coming from outside Germany. (Their relevance was limited, however, in the time period under consideration.) Our econometric setup is simple, and we could not fully disentangle self-selection into mobility to the East from demand-side factors. In addition, we have not been able to study the type of research conducted by young scientists hired in East and West. Part of our concept of an "opportunity shock" is that it does not only increase quantitative demand, but also creates space for innovative research. We are intent on analyzing whether those hired in the East were indeed more innovative in their research than those who stayed in the West, and whether the opportunity shock of German reunification also opened up opportunities for non-mainstream research, in future work.

Chapter 3

The Leap into the Unknown: Is Thematic Mobility Punished or Rewarded in Science?

3.1 Introduction

Scientific progress is driven by researchers' curiosity. A scientist's motivation to discover new knowledge is what makes researchers start new projects and see them through to the end. Scientific success, i.e. the actual discovery of new knowledge, does not only depend on researchers' perseverance, though. In order to discover new knowledge, existing knowledge has to be recombined in a useful way (Nelson and Winter, 1982), which means that a researcher is required to have access to an existing stock of knowledge, have a certain level of ability in order to perform the task at hand, and be creative enough to recognize the opportunity for new research.

These personal characteristics, however, may not always be complementary to each other. One major criticism of the academic system has long been that scientists focus too strongly on a specific research topic, becoming experts in a certain field but at the same time losing their ability to think outside the box. Ziman (1987) describes scientists as "highly specialized and resistant to change". Such high specialization comes with the perceived advantage of security, with the next study always lined up and minimal uncertainty towards its feasibility and publishability (Gieryn, 1978).

While for the individual researcher, a high degree of specialization may at first seem useful, it can be argued that it has stronger negative effects on the advancement of science as a whole, and maybe even on the individual level. Researchers who are thematically mobile, i.e. not stuck to a certain research niche, and instead open to diverse ways of thinking, can be seen as drivers for the emergence of new research fields. Without scientists thinking outside the box, fields like nanotechnology or bioinformatics could not have emerged (Lawson and Soós, 2014). In turn, such diversity in thinking may lead to major innovations and economic progress (Grabher and Stark, 1997). On the individual level, thematic mobility can also be argued to enhance researchers' creativity and productivity (Kuhn, 1962; Stirling, 2007).

There are a number of studies that have focused on thematic mobility so far. They can be split into categories according to the methods used to measure thematic mobility, or according to the phenomena they try to explain. The groundwork for such studies was laid in the sociology of science, where observations were made and general theories were posed concerning, among other issues, the reasons for and effects of thematic mobility (Merton, 1973; Gieryn, 1978; Ziman, 1987).

So far, thematic mobility in science has mainly been examined in the context of interdisciplinary research (c.f. Rafols and Meyer (2007); Porter and Rafols (2009); Van Rijnsoever and Hessels (2011); Lawson and Soós (2014); Yegros-Yegros et al. (2015); or, for a comprehensive literature review with a focus on bibliographic methods, Wagner et al. (2011)).[1] This is due to the fact that, for a long time, interdisciplinary research has been seen as a desirable result of policy initiatives, with the hopes of this type of research leading to economic as well as social progress (Rafols and Meyer, 2007).

Even in the relatively clear context of interdisciplinary research, thematic mobility has been a hard-to-capture concept. This can be seen in the diversity of data and measures used to show the-

[1] Rafols and Meyer (2007) criticize the terminology of inter-, multi-, trans- and cross-disciplinarity due to ambiguity and instead suggests using the term *cognitive diversity*

matic mobility in empirical studies. Some studies rely on observations from case studies (Shinn and Benguigui, 1997; Rafols and Meyer, 2007) or surveys (Crane, 1965; Garvey and Tomita, 1972; Van Rijnsoever and Hessels, 2011), others use publication data to construct bibliometric indicators (Porter and Rafols, 2009; Borjas and Doran, 2015a; Yegros-Yegros et al., 2015). These bibliometric indicators have become more and more popular with the rapid growth in computational power, coupled with better access to and quality of publication data. These measures usually utilize data on keywords, co-authorships, collaborations, citations or co-citations, and different tools are developed to become independent of journal classifications, which can be highly imprecise (Rafols and Meyer, 2007; Wagner et al., 2011).

One relatively new way of classifying publications into categories, and subsequently measuring thematic mobility, is text-based structural topic modeling. So far, this approach has rarely been utilized in research on science and innovation (Blei and Lafferty, 2007; Hall et al., 2008; Blei, 2012; Kaplan and Vakili, 2015; Myers, 2018; Rehs, 2019), but promises a far superior classification of research works, based on Kuhn's (1962) idea that the vocabularies used by researchers shift with a shift in research focus. Topic modeling approaches are computationally much more demanding than more traditional bibliometric measures, but in recent years it has become more and more feasible to utilize such tools to use publications' titles, abstracts or even full texts to classify them.

So far, the literature on thematic mobility has shown that science is becoming ever slightly more interdisciplinary (Porter and Rafols, 2009), that young (Rappa and Debackere, 1993), female and applied (Van Rijnsoever and Hessels, 2011) researchers or such who come from less renowned universities (Crane, 1965) are more likely to be thematically mobile, that those researchers who are forced to be thematically mobile are less likely to stay in science and publish well (Borjas and Doran, 2015a), and that there seems to be an inverted U-shape relationship between interdisciplinarity of a research project and the citations of resulting publications (Yegros-Yegros et al., 2015).

In this study, I use a sample of highly-skilled junior researchers in German physics to show the relationship between voluntary thematic mobility and citations as well as the probability to receive awards. In doing so, I add to the existing literature by filling in some of the gaps identified so far. In previous studies, the measures used to identify thematic mobility/interdisciplinarity are mostly based on (co-)citations or journal-classifications. These measures tend to be rather crude, and oftentimes depend on interpretations by the authors who use them. They mostly allow for an identification of interdisciplinarity, but cannot be used to describe intradisciplinary mobility. Only the most recent studies by Myers (2018), Azoulay et al. (2019) and Furman and Heinisch (2019) use measures that use text as data (see also Gentzkow et al., 2019), and infer their measurement of thematic mobility from changes in the vocabulary used. These measures are independent from the observing researcher's interpretations and at the same time allow to show thematic mobility within one discipline, instead of across disciplines. I will add to this strand of literature by using keyword- and abstract-text-based measures of thematic mobility.

So far, most studies in this field either focus on the reasons for or the effects of thematic mobility, Borjas and Doran (2012, 2015a), Myers (2018) and Azoulay et al. (2019) being the exception. I try to add to this literature by choosing a sample in which thematic mobility is highly likely to be voluntary, which should be expected to influence its effects.

I also decided to not only analyse thematic mobility's relationship to citations, but also to the researchers' probability to receive an award, as an alternative measure for acceptance in the scientific community. Due to the different directions of the findings from previous studies, I cannot make any assumptions as to how voluntary thematic mobility will affect the researchers in my sample. Furthermore, clear causal inference cannot be achieved through the analyses in this study, which should be kept in mind when looking at the results. This study is thus exploratory in nature, and should be seen as a stepping stone for future research.

This study is structured as follows. In Section 3.2, I discuss prior work on the topic in more detail. In Section 3.3, I describe the data and methods used to do so, Section 3.4 contains the empirical analyses and Section 3.5 concludes the paper.

3.2 Thematic Mobility of Researchers

3.2.1 Causes for Thematic Mobility

Scientists very rarely do research on the exact same topic throughout their entire academic career. Horlings and Gurney (2013), using a measure that combines publications' title-words with citations for 43 condensend-matter physicists, show that throughout the academic lifecycle, researchers work on multiple topics, and that these topics sometimes overlap. They show that thematic mobility is strongest in the postdoctoral phase, with PhD students usually working on one topic, and professors narrowing down their research focus again.

How far researchers venture between topics, however, and whether they venture into established or completely new topics, depends on a number of factors, and while academic age matters, it is only one of these factors, and thematic mobility may happen in all career stages for different reasons. One can differentiate between push- and pull-factors that drive thematic mobility. In this context, push-factors for thematic mobility would be some kind of intrinsic motivation to switch between topics, while pull-factors would be external factors that force researchers into another field.

Push-factors for thematic mobility are not as easy to define as pull-factors. They are based on a scientist's motivation to push the boundaries of science, and depend on their creativity as well as their willingness to take risks. While sheer curiosity may be a main driver here, a researcher may also hope to gain a better understanding of the "bigger picture", or push on and be the leader of a whole new research area (Gieryn, 1978; Huutoniemi et al., 2010; Lawson and Soós, 2014).

Pull-factors, on the other hand, can be much easier to observe in empirical studies. The academic job market is an interesting labor market, with universities and research institutes on the demand-side, and researchers on the supply-side. It is characterized by a high supply of researchers competing for a relatively low number of permanent jobs, i.e. relatively low demand. Merton (1957) first stated that scientists compete for priority in science, with reputation as the reward, meaning that a scientist who first manages to publish new results will be more recognized in the scientific community, and subsequently have higher chances of obtaining funding or reputed jobs. This competition for priority has also been the focus of the economics of science (Stephan, 1996). The introduction of bibliometric measures for the evaluation of researchers has further escalated this matter, and lead to a publish or perish nature of the academic job market, meaning that researchers put a lot of effort into publishing their research in respected journals in order to optimize their ratings, and those who are less successful in this competition are less likely to get a permanent position in academia (Weingart, 2005).

Competition among researchers for space in highly reputed journals is thus high, and changes in supply of researchers or demand for research in a certain field has a direct effect on researchers already active in this field. Changes in demand can usually be observed by changes in funding for certain projects (Lawson and Soós, 2014). If a funding line runs out, researchers have to reorient their research (Garvey and Tomita, 1972). Similarly, researchers may feel compelled to switch their topics if their research in a specific field has been unsuccessful, or if the lab requires them to do so (Crane, 1965). Wang et al. (2018) show that the type of funding used (competitive vs. block-funding) in Japan had direct effects on the novelty of research. They show that for low-status, young researchers, competitive funding has a negative effect on the novelty of their research, and rather pushes them to remain in established fields. For older, high-status researchers, they find the opposite effect, with competitive funding increasing the novelty of research. In this study, novelty of papers is the dependant variable. So, while the differences shown give an idea about which groups of researchers are more likely to take the big risk of venturing into completely new fields, they say nothing about the likelihood of being thematically mobile between already established fields of research. Using data from the US National Institutes of Health, Myers (2018) shows that within the medical sciences, the elasticity of researchers is rather low, meaning that an increase in funding in a specific field needs to be substantial in order to motivate scientists from other fields to switch their research focus. Azoulay et al. (2011) also look at NIH-funded medical scientists, but compare the to scientists funded by the Howard Hughes Medical Institute (HHMI). The HHMI grants are explicitly set up to allow for experimentation and reward long-term rather than short-term success. They show that these HHMI-grant recipients are much more likely to explore novel fields and to produce high-impact publications than their NIH-funded counterparts.

Supply shocks can also foster or hinder thematic mobility. Borjas and Doran (2015a) use a natural experiment to analyse the effects of supply shocks on scientists. They show that after the fall of the iron curtain, a significant number of soviet mathematicians moved to the U.S. and started working in academia. This meant that the supply of scientists in certain mathematical sub-disciplines increased abruptly, and competition for publication space in reputed journals grew immensely. As a consequence, less established American mathematicians moved their research focus away from the fields that experienced the soviet influx, and towards less competitive fields (Borjas and Doran, 2015a).

Another possible shock to the supply of a certain research field is the introduction of new technologies that open up new possibilities of research, or make research cheaper. Furman and Teodoridis (2018) use the introduction and subsequent hacking of Microsoft Kinect, which could then be used as a cheap but useful motion-tracking device, as a supply shock in science. They find that this indeed had a strong impact on the scientific landscape, with researchers who were already using motion-tracking technology branching out their research focus into fields that are new to them (but not necessarily novel altogether), and other researchers who had never used motion-tracking technology before suddenly starting to use this new device in their research.

Both Azoulay et al. (2019) and Furman and Heinisch (2019) use the death of researchers as a supply shock in science. Azoulay et al. (2019) show that when a star-scientist dies, space within the field opens up, and is taken up by outsiders, who previously did not publish in the same field, and that this is a likely time for paradigms to be broken and new kinds of research being introduced. Furman and Heinisch (2019) show the effect the death of an advisor has on former PhD students. They find that advisees who had some time to establish themselves in science orient back to their advisor's research agenda after their death, which can be interpreted as them filling in the spots their advisors left empty.

3.2.2 Scientific Career Stages and Thematic Mobility

Traditionally, typical scientists' careers can be roughly split into three phases. First, the PhD training phase, second, the postdoc phase, and third, the tenured phase. Each of these phases is characterized by different possibilities and obligations (Horlings and Gurney, 2013).

The PhD phase is the career stage during which a scientist is introduced to the ins and outs of academia. The research area of a PhD student is more or less predetermined by their advisor, who has a major influence on them in these formative years. This goes beyond the setting of a research agenda, as the advisor also grants their student access to their research network (Long and McGinnis, 1985). Additionally, they transfer non-codified knowledge to their advisees that is important for working in academia (Buenstorf and Geissler, 2014) and subsequently training students of their own (Malmgren et al., 2010). All this socialization during the PhD phase has a major impact on the student's later career (Hottenrott and Lawson, 2017), however, the possibilities for thematic mobility *during* the PhD phase are relatively slim.

During their postdoctoral phase, researchers have to distinguish themselves in order to maximize their chances of obtaining a tenured position. One way to make this happen is to expand coauthor networks and branch out the research focus. So this stage is where researchers are most likely to be thematically mobile, while in the following tenured stage, with other obligations taking up more time and a reduction in the need to prove themselves, researchers tend to again focus their research agenda more strongly (Horlings and Gurney, 2013).

The importance of career stages for the likelihood of thematic mobility has been shown by Horlings and Gurney (2013) in a study of 43 condensed matter physicists. Their findings go in line with previous theoretical assumptions and empirical studies. Kuhn (1962) postulated that scientific communities share certain *paradigms*, which are seen as a basis of research within this community, and are not interfered with by its members. He states that the breaking of such paradigms, which may lead to scientific revolutions and the origin of new disciplines, is incumbent upon young researchers, who are not yet indoctrinated. In the same vein, Rappa and Debackere (1993) show that it is actually junior researchers who are most likely to tackle new fields. They use the time since graduation to define junior researchers, and find that 46 per cent of researchers who joined the new field of neural networks in the mid-late 1980s had between zero and nine years of professional experience after their PhD. This goes in line with Wang's (2018) findings, part of which were already discussed above. They find that young researchers are overall more likely to plunge into newly established fields, but that a focus on competitive funding mitigates this effect.

Wray (2004) finds that in the field of bacteriology, it was middle-aged rather than young scientists who were most likely to contribute to a new field. However, his definition of young scientists does not regard the career stage, but he instead looks at the researchers' actual age. He then defines researchers younger than 36 years as young, and researchers aged 36-45 as middle-aged. Since a lot of researchers in their postdoctoral career stage fall into this age group, Wray's (2004) findings that middle-aged scientists are most likely to tackle new fields do not contradict the results from the previously mentioned studies.

In conclusion, research so far shows that, disregarding the reasons for thematic mobility, researchers seem to be most likely to be thematically mobile in their postdoctoral career stage. This seems to especially hold for thematic mobility into new fields that are not yet fully established.

3.2.3 Effects of Thematic Mobility

Thematic mobility can have positive as well as negative effects on a researcher. Page (2008) presents an extensive theoretical argumentation for why diverse groups are needed in all strands of society, science among them, and how they should be able to outperform highly specialized experts. In a similar vein, Stirling (2007) argues that diverse (interdisciplinary) research groups are better able to deal with more complex problems and overcome unexpected challenges.

On the other hand, thematic mobility comes at a cost. Most obviously, there are transaction costs. In the context of interdisciplinary research, these costs go along the coordination of researchers from different fields that need to 'speak the same language' (Cummings and Kiesler, 2005; Yegros-Yegros et al., 2015). These transaction costs are relevant even for researchers working on their own, because in order to get into a field new to them, they need to understand the terminology and get an overview over prior work in the field, or, if the field does not yet exist, go to even greater lengths to establish some groundwork.

Additionally, thematic mobility can have another disadvantage for the researcher, in the form of a lack of acceptance in the scientific community. Here, Kuhn's (1962) paradigms become relevant again. Researchers who are thematically mobile tend to break with these paradigms, which will lead to a loss of reputation within the establishment. Using interviews, surveys and case studies, Bruce et al. (2004) report multiple factors that, according to researchers, discourage interdisciplinary research. Among them are "discrimination by referees against interdisciplinary research proposals and publications" as well as "lack of opportunities to publish research results in high ranking refereed journals" (Bruce et al., 2004). This suggests a low acceptance of such research projects within the scientific community (Yegros-Yegros et al., 2015).

Due to these counteracting positive and negative effects of thematic mobility, and its possible causes mentioned in Section 3.2.1, studying the effects on an individual level is not a simple task. It can be expected that voluntary thematic mobility (caused by push-factors) has different effects than involuntary thematic mobility (caused by pull-factors). Few studies so far were able to distinguish these kinds of effects.

Borjas and Doran (2012, 2015a) show that American mathematicians' involuntary thematic mobility, caused by an influx of Soviet scientists, had strong negative effects on these Americans. They were pushed to less reputed universities and, at the same time, other fields of studies, or they left science altogether, and their chances of publishing in highly reputed journals were reduced drastically. Borjas and Doran (2012, 2015a) could not find positive effects of this involuntary thematic mobility.

In his study concerning US medical researchers, Myers (2018) shows that research funds that request proposals on very specific topics, which motivate scientists to be thematically mobile, may seem expensive at first, but, if enough grant money is offered, they are effective at making researchers thematically mobile. With a quick back-of-the-envelope calculation, he argues that this is indeed a cost-effective way to generate new high-quality publications.

Regarding scientists who moved their research focus to fill the space left behind by dead star scientists, Azoulay et al. (2019) find that these mobile scientists' new publications are disproportionately likely to be highly cited. They explain this with these scientists being the ones who overthrow paradigms, and lead the field in a new direction.

Some other studies have looked at the effects of thematic mobility, although this was mostly done in the context of interdisciplinary research projects, with the effects measured on the paper-level (not on the researcher-level), and the causes for the thematic mobility were mainly disregarded. Among these studies, thematic mobility/interdisciplinarity is measured in different, often rather coarse ways, and the effect is mostly measured as some type of citation impact on the respective paper, but not on other papers by the same authors that may follow.

The findings of these studies so far are inconclusive. Some studies find positive effects of interdisciplinarity on citations (Steele and Stier, 2000; Kwon et al., 2019; Okamura, 2019), some find a negative impact (Larivière and Gingras, 2010; Wang et al., 2017), some find no effect (Rinia et al., 2001; Adams et al., 2007), and some find signs for an inverted-U-shape relationship between interdisciplinarity and citations (Uzzi et al., 2013; Yegros-Yegros et al., 2015). Looking at these studies, novelty is often used to explain the positive or, respectively, the negative effects, but novelty is mostly just an assumption and not properly tested. Either way, some of these studies plainly contradict each other.

3.3 Data and Methods

For my analyses, I decided to focus on Emmy-Noether grant recipients in German physics. I use a keyword-similarity measure as well as a topic-modeling approach to construct measures of thematic mobility between papers published before and after the dissertation. Controlling for a number of variables, I then estimate the effect thematic mobility has on citation counts as well as the grant recipients' probability to be awarded with scientific prizes.

The Emmy-Noether grant program was established in 1999 by the German research foundation ("Deutsche Forschungsgemeinschaft" - DFG), and aims to boost highly qualified junior researchers on track to becoming professors. It is aimed at German as well as foreign postdoctoral researchers who have finished their PhD within the last two to four years. It should thus perfectly capture those researchers most likely to be thematically mobile (see Section 3.2.2). Emmy-Noether grant recipients are supposed to be top of their cohort, and the grants are simultaneously a very prestigious award and a source of comparatively generous funding. Grant recipients receive up to six years of funding for an independent research group. The entry barriers are high, and applicants are expected to have already published some work in top journals (Lehmann-Brauns, 2005). These grant recipients are thus highly qualified postdoctoral researchers who are likely to stay in academia, and they can choose the focus of their groups' research at their own will. It is thus highly likely that thematic mobility within this group is of a voluntary nature, and not born out of necessity.

I use data from DFG GEPRIS, the DFG's online database providing information on DFG-funded research projects. Here, I collected information on all Emmy-Noether grants awarded in physics since the beginning of the funding line in 1999. I focus on physics because it is a highly diversified field with a lot of room for intradisciplinary thematic mobility, and because in physics, researchers usually start publishing early in their PhD phase and publish more than, for example, social scientists, which allows me to use bibliometric measures for my analyses. I identified 212 grant recipients between the years of 1999 and 2018. I then used the catalogue of the German National Library (DNB) to identify the German researchers' dissertation years and universities, and manually looked for information regarding foreign researchers' dissertations online. I found dissertation data for 197 of the 212 grant recipients. Since I need the dissertation year and university for my analyses, I dropped the remaining 15 recipients from my sample.

In a next step, I matched this data to Thomson Reuters' Web of Science to obtain publication data. The first link was made through a surname-firstname/initial combination alone, and then the list of publications was manually cleaned up. This strategy was necessitated by the incompleteness of the Web of Science data (oftentimes, there are incomplete names or missing values for author affiliations) and the nature of my analysis. I could not use data matching algorithms, because these would have run a high risk of either excluding publications that are thematically distant from the author's previous publications, or including false matches that might imply a higher degree of thematic mobility than there really is. I thus used the researchers' online CVs and publication lists to find the correct matches in Web of Science through author name, article title, article year, and author affiliation. In order to make analyses for post-dissertation thematic mobility possible, I excluded all authors for whom I could not find any publications before the dissertation, or whose publication record ended sooner than five years after their dissertation. This lead to another 29 grant recipients being excluded, and I ended up with 18,143 publications for 168 authors. The high number of publications is due to a number of

Table 3.1: Descriptive Statistics

Statistic	N	Mean	St. Dev.	Median	Min	Max
female	168	0.179	0.384	0	0	1
institution change	168	0.952	0.214	1	0	1
theoretical physics	168	0.542	0.500	1	0	1
dissertation year	168	2004	4.928	2003	1995	2012
dissertation abroad	168	0.190	0.394	0	0	1
EN start	168	2008	5.885	2007	1999	2018
award received	168	0.179	0.384	0	0	1
publication stock 3 years after dissertation	168	29.804	51.404	19	4	387
weighted publication stock 3 years after dissertation	168	3.470	1.894	3.2	0.451	10.260

Note: Descriptive Statistics

grant recipients working in research collaborations, in which each member is given authorship on every publication. In my main analysis, I try to control for this by using author-weighted publication counts, but as a robustness check, I also provide analyses with these authors excluded in the appendix.

For the 168 authors in my main sample, I searched online for press releases or CV entries concerning awards received. I restricted my search to prizes received at least five and at most ten years after the dissertation, and was able to find 30 of the grant recipients to have received such prizes as the "Ludwig-Biermann-Foerderpreis" of the German Astronomical Society, the "Roentgen-Preis", or the "Hertha-Sponer-Preis" of the German Physical Society in the relevant time. All of these awards have in common that they are not aimed at PhD-students, but rather at more senior researchers, and that they are highly prestigious.

I also collected further information on the authors, such as gender, institute changes from dissertation university to the institute at which they lead their Emmy-Noether group, a differentiation between theoretical and applied physics, and the start of the Emmy-Noether group's funding. Descriptive statistics can be found in Table 3.1.

The sample is dominated by male physicists, with only 30 of the 168 grant recipients (17.9 per cent) being female. Almost all of the recipients had a change of institute between their dissertation and Emmy-Noether research group. About half of the sample was active in theoretical physics, the other half in applied physics. 36 of the grant recipients (19 per cent) received their PhD outside of Germany. Looking at the publication stock of each grant recipient three years after their dissertation, the difference within the sample becomes very clear, with the number ranging from 4 to 387. This difference becomes much less pronounced, though, once the number of publications is weighted by the number of authors.

In this study, I use two different methods to measure thematic mobility. First, I construct a more conservative measure based on keyword-similarity (as used by Azoulay et al. (2019) and Furman and Heinisch (2019)), second, I use a topic-modeling approach (as used by Blei and Lafferty (2007); Blei (2012) and Rehs (2019)) based on abstract texts, in order to be able to capture changes in sub-topics in even more detail. For both measures, I estimate a similarity/distance measure that compares publications up to the year of dissertation with those that come in the five years after. This allows me to show whether researchers stayed within the same topic after completing their PhD, or whether and to what degree they moved their research focus during their postdoctoral studies.

For the keyword measure, I calculate the average number of keywords that are used both before and after the dissertation for each author. Azoulay et al. (2019) use this measure to calculate the overlap of keywords used by researchers with those used by deceased star scientists, and Furman and Heinisch (2019) use it to calculate the overlap of keywords used by dead advisors and their advisees. While Azoulay et al. (2019) can rely on PubMed keywords, which are assigned by outside indexers who can be expected to be objective, Web of Science keywords, which are used by Furman and Heinisch (2019) and myself are assigned by the authors themselves. This comes with the disadvantage that authors may chose keywords out of habit, meaning they do not change the keywords they assign even when they shift their research focus, which may lead to an underestimation of thematic mobility when using this measure. Nevertheless, I use this measure as the 'conservative' measure for thematic mobility, to lay the groundwork for my analyses. I slightly adapt the measure by multiplying the keyword-similarity measure with -1, which then makes it a distance measure instead of a similarity measure, and makes the interpretation in this context easier.

In a next step, using a text-based structural topic modeling approach on the grant recipients' publications' abstracts allows me to avoid the problems that come with the use of author-selected keywords. Structural topic modeling allows to discover topics from text, by automatically classifying a (not necessarily pre-specified) number of topics, and assigning each word a probability of belonging to each topic. I use an approach similar to Rehs (2019) for the training of my topic model. In the first step, I draw 20,000 random publications from Web of Science that are classified as physics publications, and process their abstracts with a number of text-mining-tools such as stopword removal, stemming and n-gram detection. The training of the topic model then begins with spectral initialization (Arora et al., 2013), a machine learning algorithm that uses the (processed) texts of the abstracts to specify 79 topics (this number is not preset, and is the number of topics the algorithm deems optimal). Note that all of these topics can be seen as somehow related to physics, and that the topics are probably not the same as the subtopics an expert might chose to define. Each word (or *n-gram*, a common combination of n words) is then given a certain probability of belonging to each topic, and each topic is given a probability of having certain words included.

I can then take the abstracts of the publications published by the grant recipients before/five years after their dissertation and, after pre-processing the texts exactly like the abstracts for the training set were pre-processed, apply a structural topic model (Blei and Lafferty, 2007; Blei, 2012; Roberts et al., 2014; Rehs, 2019). This model, based on the abstract texts, assigns each document a degree to which it belongs to each of the 79 topics. In a next step, I can calculate the cosine similarity between the topic distributions of chosen texts. This is a measure for the distance between two vectors, these two vectors in this case being the topic distributions of two papers. The cosine similarity ranges from zero to one, and at the two extremes it takes the value zero when there is no similarity between the topic distribution of two papers, and one if they are identical. For each grant recipient, I calculate the cosine similarities between all the papers published before the dissertation and those published in the first five years after the dissertation. Taking the average of these similarities, I can show how thematically mobile each grant recipient was on average in the five years after the dissertation as compared to before.

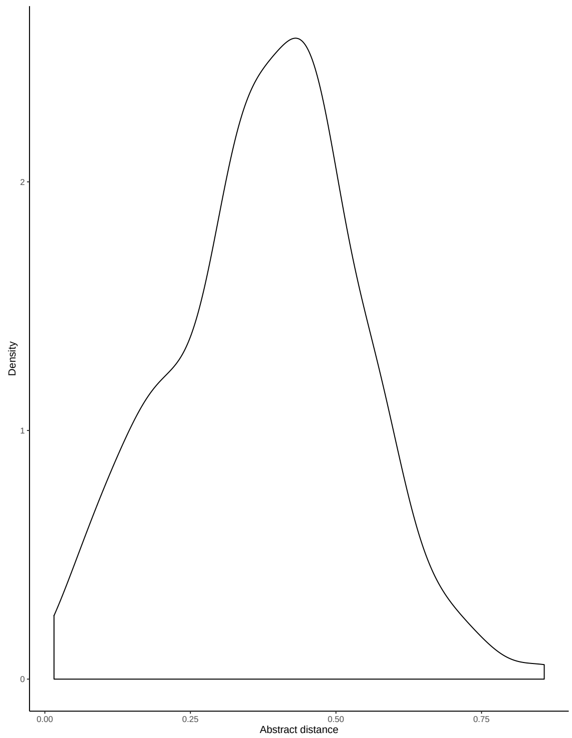


Figure 3.1: Density Plot of Average Abstract Distances

To make the interpretation easier, I subtract the average cosine similarity from one, which means that now a higher value stands for lower similarity, or in other words, a higher thematic distance. This leads me to a variable that states for each author, how far away they moved from the topics assigned to them by their PhD advisors in their early postdoctoral phase. The density plot in Figure 3.1 shows the distribution of these average distances between authors' abstracts. It shows that few of the grant recipients only barely changed their research focus (with a distance close to 0), but even fewer made big changes, with the maximum distance being 0.86, and most distances lying in the 0.3-0.5 range. This can be interpreted as some thematic mobility being normal after the dissertation, but the research agenda set during the PhD phase usually not being lost completely.

3.4 Empirical Analysis

I can now use this data to analyze the differences between thematically mobile and immobile grant recipients. For each analysis, I use both the keyword distance measure (derived from keyword overlap) and the abstract distance measure (cosine distance of topic distributions) to find out whether or not they lead to different results, which would support the theory that they may not measure the same thing, and that true thematic mobility may be better measured with the more objective measure taken from the topic modeling approach.

In line with the previous literature on the effects of thematic mobility, I first measure the link between thematic mobility and citations. Since I am interested in the direct relationship between thematic mobility and citations rates, I use the (per paper) average number of citations to papers published within the first 5 years after the dissertation as the dependent variable. The analysis thus allows me to show what happens with the papers responsible for a shift in the research agenda. For all papers, I use the citations within three years after publication. This is necessitated by the recentness of the data, which means that for every year I add to the citation range, I lose observations. Using early citations should not be problematic, though, because early citations have been found to be good predictors of publications' overall impact (Adams, 2005; Bruns and Stern, 2016). Due to the necessity to look at citations over a three-year time span for papers that were published up to 5 years after the dissertation, I have to reduce my sample to researchers who received their PhD until 2009 (reliable publication data was only available until 2017). This reduces my sample for this analysis to 132 grant recipients.

The results of an OLS-analysis of thematic mobility's relationship to citations is shown in Table 3.2. Model 1 and 3 are reduced models, with keyword distance and abstract distance, respectively, being the only explanatory variables. In models 2 and 4, control variables are added. An author-weighted count of publications three years after the dissertation is added as a productivity measure. "female" is a dummy-variable taking the value 1 for female grant recipients, and further dummy variables control for whether or not there was a change in institutes between dissertation and start of the Emmy-Noether research group ("institute change"), whether the researcher is active in theoretical or applied physics ("theoretical physics"), and whether or not the PhD was acquired outside of Germany ("dissertation abroad"). To control for time-effects, I further include variables for the dissertation year and the start of the Emmy-Noether research group funding ("EN start").

I find no conclusive evidence for thematic mobility being linked to citation counts in my sample. In both model 1 and model 2, the link between keyword distance and citations is negative, but insignificant. In model 3, abstract distance again is negatively but insignificantly linked to citations, while the negative link is weakly significant in model 4 ($p<0.1$). It does not seem like voluntary thematic mobility had an effect on the citation counts of the grant recipients in my sample, or if at all, a rather small one.

Looking at the control variables, a few coefficients jump out. Female physicists seem to be cited less than their male counterparts. Whether this is a sign for discrimination or for some sort of selection effect is not clear. Emmy-Noether grant recipients who received their dissertation abroad seem to receive more citations than their German counterparts. This could be due to the hurdles for receiving an Emmy-Noether grant being higher for foreign researchers, or because their international mobility gave them some other kind of advantage.

Table A.1 in the appendix shows the identical analysis for the sample with all authors excluded who had more than 69 publications (equal to the mean plus two times the standard deviation in this sample). The results change insofar as now, the negative relationship between keyword distance and citations becomes significant in model 2, and the relationship between abstract distance and citations in model 4 loses its significance. This supports the previous findings insofar as there seems to be a weak negative link between thematic mobility and citations, but not enough to speak of robust negative effects.

Next, I take a closer look at the relationship between thematic mobility and the acceptance in the scientific community. As a measure for this acceptance, I use scientific awards. The recipients of such awards are usually picked by senior members of the scientific community. Indeed, a small strand of literature on the economics of awards recognizes that prestigious awards are given out by award giving bodies that enjoy a high level of recognition and legitimacy, and that award recipients exhibit some

Table 3.2: Regression results explaining citations

	Dependent variable:			
	Average number of citations (over 3 years) of papers published 0 to 5 years after dissertation			
	(Model 1)	(Model 2)	(Model 3)	(Model 4)
keyword distance	-0.339	-0.547		
	(0.349)	(0.343)		
abstract distance			−8.652	−9.106*
			(5.502)	(5.368)
weighted publication stock 3 years after dissertation		−0.212		−0.236
		(0.497)		(0.498)
female		−6.399***		−6.014**
		(2.366)		(2.329)
institute change		−4.133		−3.613
		(3.968)		(3.954)
theoretical physics		−2.882*		−2.415
		(1.662)		(1.666)
dissertation year		0.337		0.563
		(0.628)		(0.628)
dissertation abroad		4.527*		4.567**
		(2.309)		(2.307)
EN start		0.190		0.015
		(0.508)		(0.511)
Constant	13.373***	-1,037.664**	18.960***	-1,131.795**
	(2.428)	(477.128)	(2.304)	(473.482)
Observations	132	132	132	132
R^2	0.007	0.162	0.019	0.164
Adjusted R^2	-0.0004	0.107	0.011	0.110
Residual Std. Error	9.705 (df = 130)	9.168 (df=123)	9.649 (df=130)	9.156 (df=123)
F Statistic	0.946 (df=1;130)	2.967*** (df=8;123)	2.472 (df=1;130)	3.014*** (df=8;123)

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from OLS regression models, standard errors in parentheses.

level of loyalty toward them and act accordingly supportive (Frey, 2007). If the members of the award giving body thus have an inherent dislike of 'new' ways of thinking, as is argued for these kinds of senior researchers, they should be skeptical towards thematic mobility, which should in turn diminish thematically mobile researchers' likelihood to receive awards.

The probability to receive an award is thus the dependent variable of my second analysis. Since I am again interested in the importance of thematic mobility within the first five years after the dissertation, I now look at the probability to receive an award five to ten years after the dissertation, because rewards received earlier might still be due to pre-mobility work.[2] The models are similar to the models in Table 3.2 in regards to the explanatory variables. I now calculate a probit model with the probability to receive an award as the dependent variable.

Results to the probit anaylsis can be seen in Table 3.3. For ease of interpretation, marginal effects at the means are presented in table 3.4. Again, no significant results can be found for the two different measures of voluntary thematic mobility. It seems like in this sample of highly qualified physicists, thematic mobility is neither positively nor negatively related to researchers' chances to be rewarded by the community. Interestingly, the weighted publication stock three years after the dissertation has a strongly significant relationship to the probability to receive an award, while it was not related to the average number of citations. An increase in the weighted publication stock by 1 unit increases the chances of receiving an award by almost 5 percentage points. Quantity seems to play a role here. Another interesting finding is that female scientists have an 18.5 percentage points higher probability to receive awards than their equally qualified male colleagues. This can at least partially be explained with certain awards being aimed primarily at women in science. So, there is a quite distinct difference in my findings regarding the relationship of gender towards the number of citations received and the probability to receive an award.

Tables A.2 and A.3 in the appendix contain results for a similar analysis for the sample without outliers (again excluding all authors with more than 69 publications). Here, the results are robust to the exclusion of outliers, do not change qualitatively and the marginal effects do not change drastically.

[2]The results are robust to a change of the time frame during which I look at the awards received. I can expand the time frame further towards the dissertation or shorten it, and the results will remain qualitatively the same. Results are available from the author upon request.

Table 3.3: Probit regression results explaining awards

	Dependent variable:			
	Award Received			
	(Model 1)	(Model 2)	(Model 3)	(Model 4)
keyword distance	−0.038	−0.007		
	(0.046)	(0.051)		
abstract distance			0.112	0.535
			(0.673)	(0.719)
weighted publication stock		0.199***		0.207***
3 years after dissertation		(0.058)		(0.058)
female		0.656**		0.659**
		(0.290)		(0.285)
institute change		0.311		0.332
		(0.605)		(0.612)
theoretical physics		−0.713***		−0.734***
		(0.257)		(0.252)
dissertation year		0.139		0.139
		(0.100)		(0.101)
dissertation abroad		−0.309		−0.300
		(0.302)		(0.299)
EN start		−0.106		−0.104
		(0.079)		(0.080)
Constant	−1.175***	−68.591	−0.964***	−71.375
	(0.333)	(63.188)	(0.281)	(62.172)
Observations	168	168	168	168
Log Likelihood	−78.500	−69.216	−78.817	−69.003
Akaike Inf. Crit.	161.001	156.431	161.635	156.007

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from Probit regression models, robust standard errors in parentheses.

Table 3.4: Probit regression results explaining awards; Marginal effects

	Dependent variable:			
	Award Received			
	(Model 1)	(Model 2)	(Model 3)	(Model 4)
keyword distance	−0.010	−0.002		
	(0.012)	(0.012)		
abstract distance			0.029	0.124
			(0.168)	(0.165)
weighted publication stock		0.046***		0.048***
3 years after dissertation		(0.013)		(0.014)
female		0.185**		0.185**
		(0.093)		(0.090)
institute change		0.062		0.065
		(0.103)		(0.101)
theoretical physics		−0.171***		−0.175***
		(0.063)		(0.061)
dissertation year		0.032		0.032
		(0.023)		(0.023)
dissertation abroad		−0.065		−0.063
		(0.056)		(0.055)
EN start		−0.025		−0.024
		(0.018)		(0.018)

Note: *** p<0.01, ** p<0.05, * p<0.1. Marginal effects at means for probit regression models, robust standard errors in parentheses.

I thus conclude that I cannot find a significant relationship between voluntary, intra-disciplinary thematic mobility and different measures of success and acceptance within the scientific community within my sample of highly qualified physicists. It could be argued that these leaders of Emmy-Noether research groups are better at distinguishing good chances from bad ones, and are thus only thematically (im-)mobile when it pays off.

3.5 Concluding Remarks

To add to the literature on thematic mobility, I used a sample of German junior physicists who received funding in the highly prestigious Emmy-Noether research line to look at the relationship between voluntary thematic mobility and different success measures. Emmy-Noether research grants offer relatively generous funding for up to six years for postdoctoral researchers. Additionally, they serve as a signal of high quality. There is thus a high competition for these grants, and grant recipients count as some of the most elite postdoctoral researchers in Germany. With the freedom they are given, it can be expected that thematic mobility only occurs out of the grant recipients' own motivation.

To control for both broader success and more precisely the acceptance for this thematic mobility within the scientific community, I analyse its relation to citations as well as to the probability to receive rewards. While there is some very weak signs for thematic mobility being negatively related to citations, I find null-effects for the probability to receive awards. This can be interpreted as a sign that these highly qualified researchers are very good in calculating the risks and expected benefits of being thematically mobile, and only shift their research focus if they expect it to pay off.

To quantify thematic mobility, I used two different approaches. The first, more conservative one was to calculate the overlap of keywords between publications, as in Azoulay et al. (2019) and Furman and Heinisch (2019). Additionally, I used a topic modeling approach (Blei and Lafferty, 2007; Blei, 2012) to be independent of author-chosen keywords and to be able to better capture within-discipline thematic mobility. I cannot return a concluding verdict, but believe that the use of text-based measures to map scientific (sub-)disciplines is highly promising, and that abstracts are better suited for this kind of work than keywords.

This study comes with some limitations. I use a within-sample comparison, and rely on the control variables capturing enough of the variance to be able to make judgements about the key explanatory variable. Although I hope to make a convincing case that what I show here is the effect of thematic mobility on researchers' success (and not the other way around), my analyses are not intricate enough to show actual causality. Hopefully, future studies can further elaborate on this. Due to data constraints, I also rely on short-term citations for my first analysis. While some literature states that short-term citations are good predictors for the long-term impact of papers, it might be that in this specific case, they are not. It could be argued that here, thematic mobility is likely to move researchers to new fields, and that the papers published in these new fields may not be cited early on, but become more and more relevant as the new field develops over time. However, one might counter that citations in the first three years are still a good measure, because scientists in their postdoctoral phase rely on quick citations to prove their value within the scientific community and hopefully get access to a tenured position subsequently, so that they cannot benefit from late citations as much. The emergence of new disciplines and early adoption by thematically mobile researchers is additionally something that could have an effect. I do not show whether a scientist moves to a new field, or just to a different, long-established field, which could have completely different effects. Adding information on this may further improve the analysis.

All in all, I add to the existing literature by providing some more information on how the reason for researchers' thematic mobility influences its effects. The literature is still not clear on the topic, and further studies should try to investigate the whole context of reasons for and effects of thematic mobility.

Chapter 4

Scientific Families in German Business Studies

4.1 Introduction

Freshly graduated PhDs find themselves confronted with the difficult choice of which career path to follow. Even if they have a 'taste for science' (Roach and Sauermann, 2010), the academic job market is highly competitive and pursuing an academic career comes with great uncertainty (for the US see Fox and Stephan (2001); for German economics and business studies see Schulze et al. (2008)). Traditionally, the scientific job market has been regarded as meritocratic, with publication-based reputation being the key component for success in academia (Merton, 1973; Dasgupta and David, 1994). More recent studies shed some more light on other factors that may have an influence on chances of junior researchers to get access to one of the highly sought-after tenured positions, and on their willingness to follow this path.

The dissertation stage is the time during which junior researchers' future careers are formed. They are able to acquire tacit knowledge (Polanyi, 1962) through interaction with their advisors and experience a socialization process which not only shapes their attitudes toward various aspects of potential careers, but also influences their research performance, as measured by publication and patenting activity (Hall et al., 2007; Fuhrmann et al., 2011; Buenstorf and Geissler, 2014; Hottenrott and Lawson, 2017). The advisor-advisee relationship has been found to be very important for the formation of junior researchers' careers (Malmgren et al., 2010; Furman and Heinisch, 2019), and it can be argued that certain 'scientific families' have a stock of non-codified knowledge that enables them to produce more scientific offspring that will remain in science than others.

In this study, I add to the literature about scientific families by showing that, even on the small scale of a sub-discipline of German business studies, scientific families matter. I show that certain researchers are able to shape whole scientific fields by 'producing' a relatively high amount of scientific offspring who in turn produce more scientific offspring than their peers. I do so by constructing a dataset in which dissertations of professors in the WK ORG subsection of the German Academic Association for Business Administration (*Verband der Hochschullehrer für Betriebswirtschaft*, VHB) are linked to their advisors. Going through multiple generations of researchers, I can show that the scientific offspring from certain scholars is disproportionately represented in today's network of professors.

4.2 Scientists' Origins

At the beginning of their academic career, a PhD student starts their studies in a research group, under the supervision of a more senior researcher. Here, they learn, among other things, how to properly conduct research, how to teach and, by being part of it, how the academic system works. With the completion of their PhD, they show that they are now able to conduct research on their own. Whether they then remain in academia or leave to work elsewhere in the public or in the private sector depends on a number of factors. First of all, the academic job market is highly competitive, with many more PhD graduates entering than tenured positions being open (Fox and Stephan, 2001; Schulze et al., 2008). This means that, if all PhDs are aiming for an academic career, the job market for tenured positions faces a supply of junior researchers that far outweighs the demand. Part of this problem is mitigated because at least some of the graduates did not intend to stay in academia to begin with, or lost their interest in an academic career during their PhD training (Roach and Sauermann, 2010, 2017). Especially in engineering and the sciences, the hiring of PhD graduates can be regarded as a means to transfer knowledge from universities to the private sector. By hiring PhDs, firms enhance their absorptive capacity (Cohen and Levinthal, 1990) and open up possible channels for knowledge flows from public to private research through the PhD's established contacts in science (Cockburn and Henderson, 1998; Zucker et al., 2002; Buenstorf and Heinisch, 2020).

It is thus not predetermined that a junior researcher, after receiving their PhD, takes on a PostDoc position and subsequently tries to obtain a tenured position. A number of studies has tried to explain why PhDs stay in science or leave. Michael Roach and Henry Sauermann (2010; 2012; 2014; 2017) use survey data to show changes in junior scientists' preferences to stay in science.[1] They show that over the course of their studies, 25 per cent of surveyed PhD students lose interest in an academic career, while only 5 per cent become more interested. They also show that this change in preferences seems not to be due to changes in (perceived) labor market conditions or inability to publish well, but rather due to changes in personal preferences toward work activities, characterized mainly by a decline in preferences for basic research work activities and the freedom to choose research projects (Roach and Sauermann, 2017). Sauermann and Roach (2014) also show that these (changes in) preferences depend on the reputation of the PhD programs junior researchers took part in, with students from more reputed programs placing a higher importance on publishing. While these studies give some insight into the junior researcher's mind in early and late stage PhD phases, they are not able to show causation. One might argue that the changes in preferences for basic research are driven by the decision (not) to stay in science, which may have completely different reasons than the ones controlled for in these studies.

A number of research papers focuses on the importance of scientific families. With the aforementioned standard practice of PhD education, their home department and especially their PhD advisor have a major influence on a junior researcher. During their doctoral education, PhD students not only

[1] The authors use the terminology of changing preferences in this study, which some economists might regard as problematic. One might argue instead that preferences do not, in fact, change, but are constant over time. However, preferences or outside conditions may not be completely known in the beginning, and may then be discovered during the PhD studies.

gain access to publications, which provide them with field-specific knowledge, but they also acquire non-codified knowledge through interaction with advisors and colleagues. Long and McGinnis (1985) first show the importance of the advisor (here called mentor) for a student's later success in research and on the academic labor market, and stress the role of socialization that happens during the PhD training. Through this socialization, they teach their students scientific norms and give them access to their networks, in which future jobs may be found.

Buenstorf and Geissler (2014) are able to support the above argument by looking at scientific families in German laser physics. They argue, using the context of evolutionary economics, that advisors not only influence their PhD students' research work, but also transfer non-codified knowledge that shapes other skills and attitudes, which in turn leads to certain advisors' students being more willing and able to stay in academia than others'. This non-codified knowledge is then handed down through the generations of researchers, with certain researchers leaving a trail of large scientific families.

This goes in line with earlier findings by Malmgren et al. (2010), who, using a genealogy of mathematicians, show that doctoral students whose advisors had a high 'fecundity' (ability to produce doctoral students), are themselves more likely to again produce doctoral students of their own (meaning they stay in academia and start training their own PhD students later on). They also show that this fecundity is correlated with other, publication based, success measures, meaning that those advisors who are able to transfer the (non-codified) knowledge necessary for success on the academic job market are, maybe unsurprisingly, also able to transfer the knowledge necessary for publishing well.

Using survey data from German science and engineering departments, Hottenrott and Lawson (2017) shed some more light on the role an advisor's attitudes play on a PhD's later career. Being able to differentiate between more specific socialization factors, they show that the strength of a research group's industry ties is positively correlated to the likelihood of the group's PhD graduates to leave academia and go work in the private sector. Similarly, they find that graduates from more applied research groups are more likely to leave academia, while ones from research groups with a stronger focus on basic research are more likely to stay. This again goes in line with the aforementioned findings by Roach and Sauermann (2017). Hottenrott and Lawson (2017) use further measures to differentiate research groups, such as patenting activity of the group head or grant sources, to show that all types of socialization influence graduates' early career paths.

Furman and Heinisch (2019) add to the discussion by looking at the unexpected deaths of advisors. They find that losing their (former) advisor can have very diverse effects on (former) students, depending on their career stage. While losing an advisor in an early career stage (shortly after graduation) can be found to have an overall negative effect, as seen by a higher likelihood to drop out of research altogether, Furman and Heinisch (2019) also find that the loss of a former advisor can actually be of profit for graduates in later career stages, who are able to fill the gap left by their deceased advisor. This further supports the assumption that PhDs are dependent on their advisors even after graduation, with fresher graduates still depending on their advisor's input and networks, and older graduates being able to profit from the specific knowledge and the established contacts their advisor left them with.

All in all, there is strong empirical support for the theory that scientific families, and the non-codified knowledge that is passed through these families, matter. Good advisors supply their PhD students with skills that help them publish well, give them access to their networks and teach them specific knowledge that helps either on the academic or on the private job market, in the meantime shaping their qualification and preferences for a future career inside or outside academia. However, studies that try to get a picture of the role of scientific families in certain disciplines are rare so far, and are of course each focused on specific (sub-)disciplines. The significance of such studies is high, though, because they can help get a picture of how important the transfer of non-codified knowledge and integration into social networks through advisor-advisee relationships actually are. In this study, I try to add to this scarce literature by showing the importance of scientific families in a sub-field of German business administration.

4.3 Business Administration in Germany

In the German academic system, business administration (*Betriebswirtschaftslehre*) is, compared to other cultures, unusually sharply separated from economics. It was first established through business schools (*Wirtschaftshochschulen, Handelshochschulen*) in the early 20th century, which were founded to teach the skills needed to run businesses in a more and more industrialised economy. Thus, in the beginning, business administration was a very practically-oriented subject. While the firm-based view of business administration remained, over time the focus shifted away from simply teaching middle-management personnel, and an independent research field emerged, with business schools being integrated into existing universities or being the basis for newly founded universities (von Colbe, 1996).

In 1921, a number of university professors in business administration founded the German Academic Association for Business Administration (*Verband der Hochschullehrer für Betriebswirtschaft*, VHB) as a tool to facilitate scientific exchange and to further establish business administration as an independent scientific discipline. After the second World War, the VHB started adding more and more members, and in the 1970s sections (*Wissenschaftliche Kommissionen*, WK) were introduced to allow a more focused scientific exchange in smaller, specialised sub-groups (VHB, 2019). In this study, I will focus on the *WK ORG*, the VHB section subscribed to organisational theory, which was founded in 1977. In 2019, it had 432 active members, ranging from professors to junior researchers still in their PhD training. My aim is to see if on the small scale of one VHB section, the importance of scientific families can already be observed.

4.4 Data

To see if scientific families matter, one has to identify advisor-advisee relationships. I identified all active members in the WK ORG who held a professorship in December 2017 from the membership register. I focused on professors to make sure that the last generation is itself active in producing new scientific offspring. I was able to identify 410 Professors in that group. I then used data from the German National Library (*Deutsche Nationalbibliothek*, DNB) to find these Professors' dissertations. The DNB catalogue contains some bibliographic information for all German dissertations since 1969, such as author name, PhD granting university, year of submission and/or publication and subject categories. It is also the basis for BibSonomy Genealogy (https://www.bibsonomy.org/persons), an online tool set in place to provide links between advisors' and advisees' dissertations. BibSonomy

Genealogy relies on user input, and allows easy linkage of dissertation titles. Efforts to have scientists enter linkages into BibSonomy Genealogy (mainly at the WK ORG's annual workshop in 2017) led to me being able to identify 80 advisor-advisee relationships in the sample. In order to find more such links, dissertation theses of the remaining professors in the sample were browsed for acknowledgements, in which the PhD student usually thanks their advisor. I was thus able to find the advisors for the remaining professors, and in a next step for some of their advisors. I also added information regarding the members' affiliation to be able to show the prevalance of certain departments.

4.5 Scientific Families in WK ORG

The resulting networks lead me to believe that in WK ORG, scientific families do indeed play a roll. Looking at one generation of advisor-advisee relationships in Figure 4.1, I can show that there are certain advisors who were able to place more of their students in science than others. Note that all nodes in this graph represent German business studies professors, so each of these researchers was successful in acquiring a tenured position, and is able to advise PhD theses. Each red node represents a professor who acted as an advisor to at least one of the professors in the sample. A connection between a red and a blue node represents an advisor-advisee-relationship. A lot of advisors in this graph can be seen to have had only one student who later became a professor (meaning their node is only connected to one blue node). Very few professors have more than three students who later become professors.

The prevalence of certain advisors becomes even more obvious when looking at a unimodal network. In Figure 4.2, I show relationships between WK ORG professors who had the same advisors. Again, each blue node represents one professor, and now a connection between two nodes signifies that both of these professors had the same advisor (if a professor in my sample was the only student of their advisor, they are not included in this graph). Here, it is even clearer to see that a vast majority of these families consist of three or less professors. There are only five families where four professors share the same advisor, two with five, one with six, and three with seven professors connected in this way.

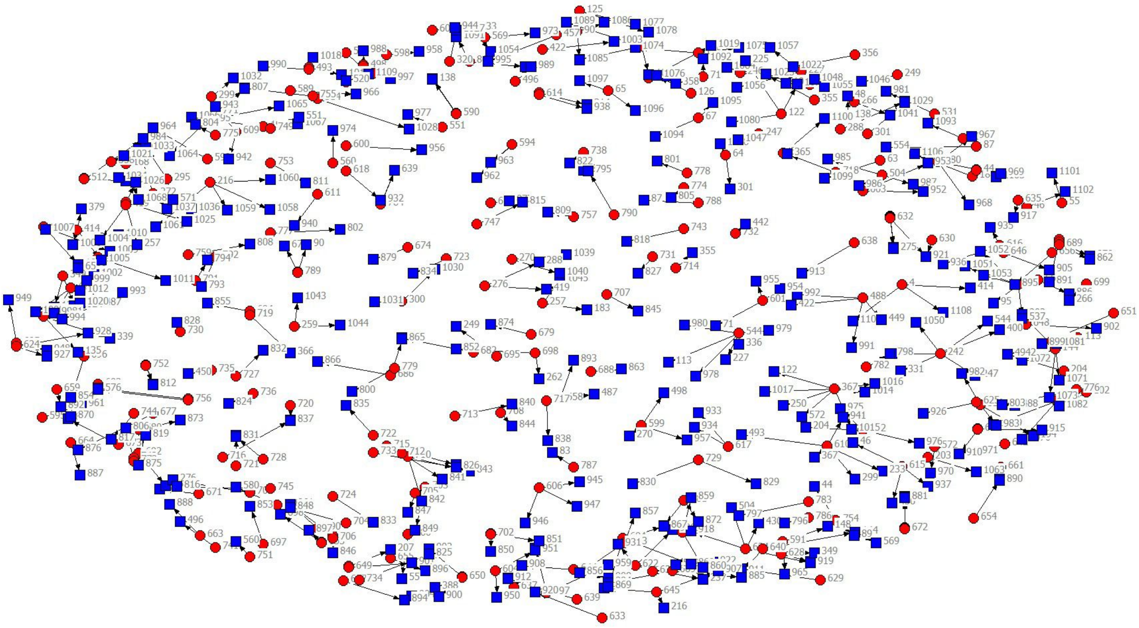


Figure 4.1: Supervisor relation; 1 generation; bipartite

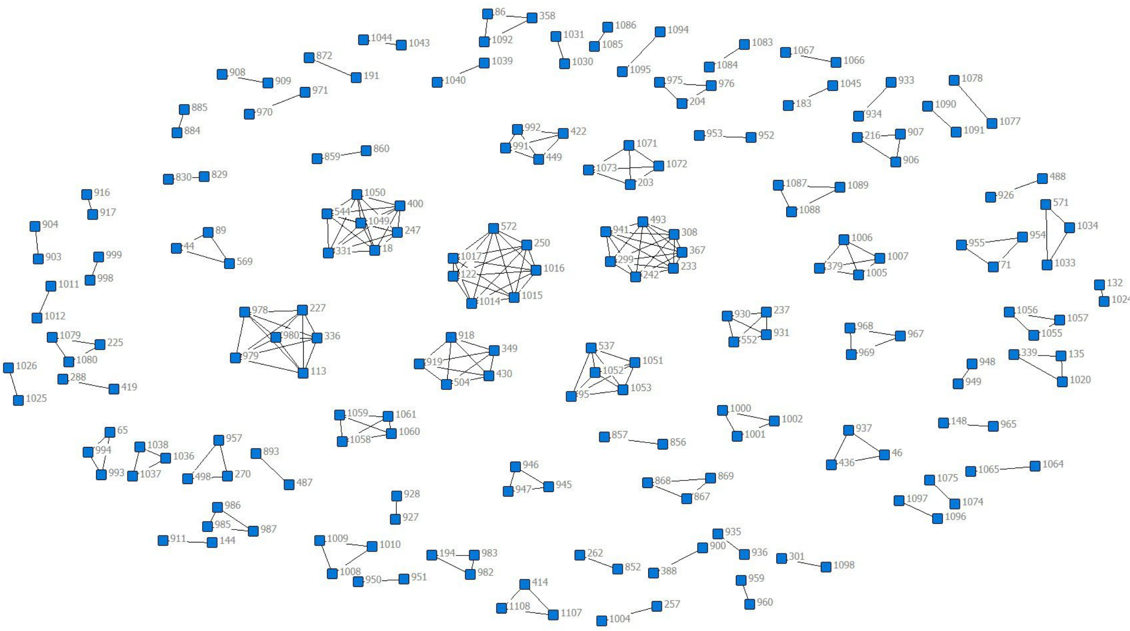


Figure 4.2: Supervisor relation; 1 generation; unimodal

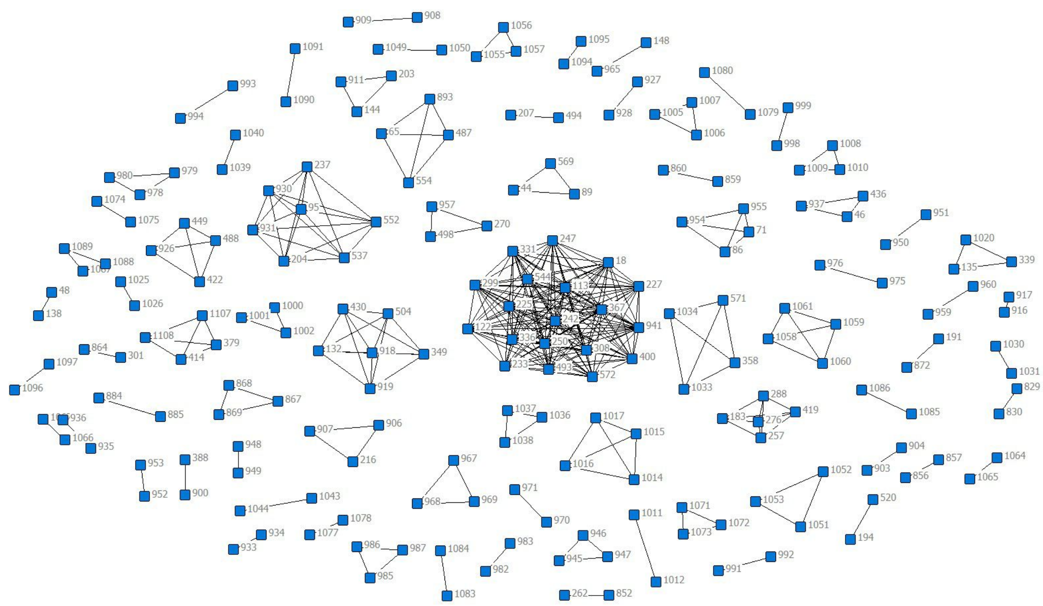


Figure 4.3: Supervisor relation; all generations; unimodal

The picture becomes even clearer if I connect families even further, connecting more than one generation. In Figure 4.3, I connect those scientific families that share the same 'ancestors', meaning that those networks from Figure 4.2 get merged where the advisors shared the same advisors. Note that this graph is not complete, due to missing data. However, I can already show that some of the stronger families from one generation get merged through their common ancestors. This is most apparent for one family, where 19 professors can be seen to be 'descendants' from one professor. This specific professor is Edmund Heinen, who became a professor of business administration at the Ludwig-Maximilans-University in Munich (LMU Munich) in 1957 , and remained there for his entire career. He was regarded as one of Germany's most prolific business administration scholars.

Looking at the geographic distribution of professors and their students who also became professors (Figure 4.4), the prevalence of two universities stands out. First, there is, unsurprisingly, LMU Munich, the graduates of which end up all over Germany. Second, scholars who got their PhD at Freie Universität Berlin also ended up being professors all over Germany. It is interesting to see that these

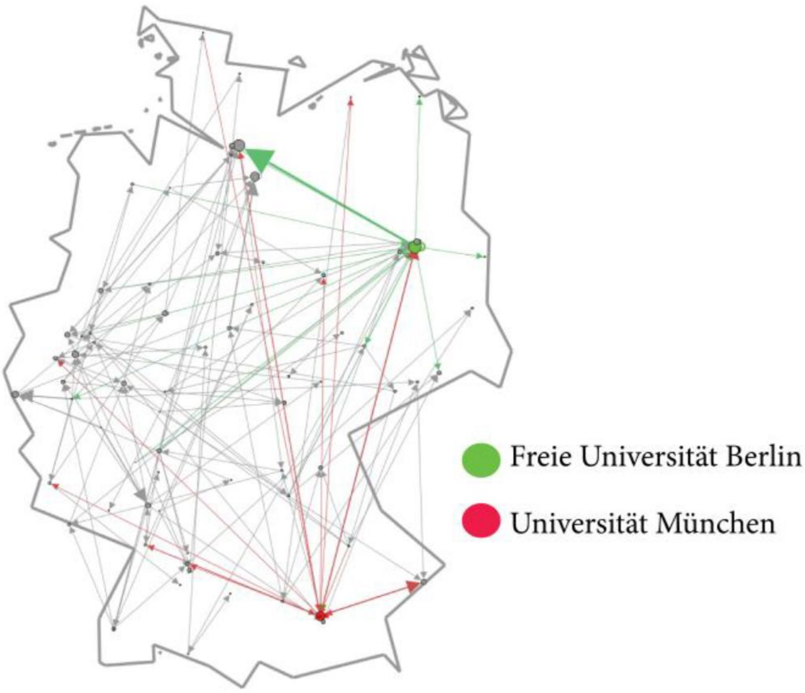


Figure 4.4: Institutional network

two universities produced a large amount of researchers who were able to acquire tenured positions, not only geographically close to their home department, but as far away as from Munich to Flensburg.

4.6 Conclusion

During their PhD training, junior researchers acquire a large amount of knowledge, not all of which is specialized scientific knowledge. Being trained by senior researchers, they also gain non-codified knowledge, which helps them in their future careers. The decision of what to do after the PhD is highly influenced by what researchers do and learn in their PhD phase. Certain professors are able to instill in their students the will to follow an academic career, and at the same time supply them with the skills and knowledge necessary to do so. If they are particularly successful with this, their former students can again do the same thing with their own PhD students. Thus, the prominence of certain scientific families is important for the understanding of scientific disciplines.

In this study, I show that in the organisational theory subsection of German business administration, one can very well see the importance of a few departments and scientific families. One scholar, Edmund Heinen, was especially successful in producing scientific offspring who in turn did the same. Even after his death, a large part of German business scholars can trace their roots back to him. If the picture so far has any predicting power, this trail might become even more dominant over time, if his advisees' advisees also manage to stay in science.

This study comes with a number of limitations. My starting point was a member register of the WK ORG, which only gives a snapshot of part of Germany's business administration researchers. The networks I show can be expected to be much more interwoven with the rest of the German speaking business administration research community, which might change the (relative) size of certain sub-networks. However, I do believe that the finding of the relevance of certain scientific families might transfer on the grander scale. There may not be one family as prominent as can be seen here, but the variance in sizes of networks will probably remain the same. I was also not able to reconstruct networks all the way back to the beginnings of business research, due to missing availability of dissertations. If one was able to do that, maybe some of the bigger families could be shown to be connected after all. Further research in this direction should be highly encouraged.

I furthermore simply look at the presence and standing out of scientific families in a descriptive way. I cannot make any claims as to why certain families are that much more dominant. This might be explained through the relevance of tacit knowledge, or it might simply be that certain advisors are far better connected than others, and can thus ensure their advisees' placement at universities. I also do not discuss whether this is a good thing or a bad thing. If scholars with a similar background are more similar to each other, one might argue that the prevalence of certain families reduces diversity, which might be counterproductive (Boschma, 2005). Further research in this direction is also highly encouraged.

Chapter 5

Proximity and Learning: Evidence from a Post-WW2 Intellectual Reparation Program

5.1 Introduction

The past decades have witnessed radical changes in information technology and communication patterns. But even though long-distance communication has become easier, faster and drastically less expensive, there is little to suggest that geography has lost its economic relevance. Production activities are unevenly distributed across countries and regions (Ellison and Glaeser, 1997; Duranton and Overman, 2005), and innovation activities remain highly concentrated in space (Audretsch and Feldman, 1996; Feldman and Kogler, 2010). At the same time, property values in innovation hubs

This chapter is based on joint work with Guido Buenstorf and Dominik Heinisch.

such as Silicon Valley are increasing to ever higher levels, attesting to the economic benefits of being located there. Agents also continue to incur vast amounts of costs to overcome geographic distance. In the United States alone, the number of passenger miles in air travel has increased by more than 30% from 2001 to 2015 (U.S. Bureau of Transportation Statistics, 2017).

Not only do persistent geographic imbalances and substantial travel costs suggest that the "death of distance" (Cairncross, 2001) was announced prematurely. They also resonate with a long line of insights that date back at least to Alfred Marshall's (1920) notion of localized knowledge spillovers. Since then, countless studies have found that knowledge flows may be restricted by geographic distance. A straightforward explanation for the localized nature of knowledge is that not all knowledge is perfectly codified, and transfer of non-codified knowledge requires face-to-face contact and interactive learning (Polanyi, 1966; Foray, 2004). Empirical evidence indicates that this holds for a variety of knowledge flows including firm-to-firm learning (Jaffe et al., 1993), knowledge transfer from public research to the private sector (Jaffe and Trajtenberg, 1996) as well as the diffusion of scientific knowledge (e.g., Helmers and Overman, 2017).

The localized nature of knowledge provides an economic rationale for individual mobility. However, mobility alone may not be sufficient to enable knowledge transfer, as learning also requires common prior contextual knowledge allowing for mutual understanding (Cohen and Levinthal, 1989). In addition, the willingness and ability to learn from others may depend on trust and mutually shared values (Granovetter, 1985). Empirically disentangling cognitive and social factors from the role of geography in the transfer of knowledge has proven exceedingly difficult. One reason is that the various dimensions of distance (or proximity) tend to be associated. For instance, replicating the seminal analysis of patent citations by Jaffe et al. (1993), Breschi and Lissoni (2009) have shown that a substantial fraction of localized knowledge flows reflect intra-regional labor mobility and localized social ties. Geographic proximity also tends to be associated with similarity in formal and informal institutions, and likewise in the curricula of education systems. A second complication in empirical identification is that geographic, cognitive and social proximity are often not exogenously given, but are actively sought by agents attempting to acquire knowledge. Mobility is influenced by deliberate choices, and so are the formation of social ties as well as educational decisions conditioning an agent's ability to understand information about a given field of knowledge.

Against this backdrop, the purpose of this paper is to provide new evidence on the role of cognitive and social factors in shaping the effects of geographic proximity on individual learning. Our empirical analysis is based on unique historical evidence about involuntary short-term migration induced by a post-World War 2 intellectual reparations program. In this empirical context, different dimensions of proximity can be distinguished in an unusually clear-cut way. In addition, mobility was unexpected and involuntary, which attenuates potential biases from self-selection.

Intellectual reparations programs denote post-WW 2 attempts by the Allied countries to acquire useful knowledge from the defeated countries, in particular Germany (Gimbel, 1990b). During the final war years and following their victory in 1945, Allied forces secured large amounts of blueprints, samples etc. from corporate R&D laboratories in Germany. In addition, German scientists and engineers themselves became part of the intellectual reparations. In a variety of programs, highly educated Germans were taken to France, the Soviet Union, the U.K.or the U.S. to be interrogated about their fields of expertise. It is this forced migration of German experts that our empirical analysis focuses upon. Specifically, we study the subsequent invention activities of German experts (mostly industrial scientists and engineers) who were, under the auspices of the BIOS ("British Intelligence Objectives Sub-Committee") program, detained in Britain and interrogated by U.K. company representatives. Rich mutual knowledge exchanges and systematic teaching and learning activities among the detained Germans have been documented.

Our identification strategy exploits the fact that the detention of German experts in Britain, and their interviews at British firm sites, enforced geographic proximity on their interactions. Given the involuntary character of the detention, potential biases from self-selection into the mobility "treatment" are minimized. The program moreover aimed at "exploiting" (Gimbel, 1990b) German knowledge. It was not intended to provide them with learning opportunities, and rather than selecting "high potentials" who could be expected to benefit most, it targeted specialists with expertise in very specific fields that were of interest to individual British companies. In addition, cognitive and social factors can be separated rather clearly in our empirical context. Cognitive proximity was high between German specialists and the British firm representatives by whom they were interviewed, but low within the group of detained Germans, who came from diverse disciplinary and organizational backgrounds and engaged in rich intellectual exchange. In contrast, the degree of social and institutional proximity was high among the detained German experts, but low between the detained Germans and their British interrogators.

Our results suggest that despite the involuntary nature of their mobility, participation in the BIOS program left durable traces in the subsequent patenting activities of the involved German experts. Their likelihood of interacting with U.K. partners increased after the detention, and their subsequent productivity as inventors exceeded that of inventors in comparable control groups. These findings indicate that the German experts gained valuable knowledge from their interaction with U.K. firm representatives. In contrast, there is no evidence suggesting that the interaction with other detained Germans exerted a relevant influence on their subsequent activities or their patent performance. These patterns are consistent with a substantial importance of cognitive proximity, while they do not suggest that social factors played an important role in the interpersonal transfer of knowledge in our empirical setting.

The remainder of this paper is structured as follows. In Section 5.2 we discuss relevant prior work and develop testable hypotheses to guide the empirical analysis. Section 5.3 introduces the historical context of the analysis. Our data are presented in Section 5.4, while Section 5.5 discusses the empirical analysis and its results. Section 5.6 concludes.

5.2 Interpersonal Transfer of Knowledge

5.2.1 Geography, Mobility and Learning

Numerous studies show that not all economically relevant knowledge is a public good. Empirical work using a variety of data sources and methods finds that knowledge flows tend to be localized, i.e. they are more pronounced within than across geographically defined regions. Apparently, there are significant impediments to the transfer of knowledge across geographic space. Jaffe et al. (1993) first used patent citations as an indicator of knowledge flows and showed that a disproportionate number of citations refer to co-located patents (at various geographic scales). Other authors have arrived at similar conclusions (e.g., Audretsch and Feldman, 1996).

Knowledge is geographically sticky because not all relevant knowledge is perfectly codified, and knowledge transfer requires face-to-face contact and interactive learning (Polanyi, 1966; Foray, 2004). Co-location facilitates chance encounters allowing for interactive learning. It also reduces the cost of deliberate interaction. To allow for face-to-face contact with distant partners, agents may permanently or temporarily move to where these partners are located. Powerful effects of migration and mobility on the exchange and geographic transfer of knowledge have been demonstrated. Migrating inventors not only acquire new knowledge at their new location. Through pre-existing personal relationships they may also become conduits of knowledge flows back to their home countries (Agrawal et al., 2006). In the context of academic research, it has been shown that the productivity of scientists increases after migration (Franzoni et al., 2014). Even short term mobility such as scientists' research stays abroad can lead to beneficial learning and long-lasting network extensions (Jöns, 2009).

Based on prior evidence that imperfect codification causes knowledge to be localized and geographically "sticky", and that mobility allows agents to tap into new sources of knowledge, we predict the following effects of mobility on agents' innovation activities:

Hypothesis 1. *Mobility provides new opportunities for interactive learning, on which mobile individuals draw in their subsequent knowledge-creating activities.*

Hypothesis 2. *Mobility provides new opportunities for interactive learning, which increases the post-mobility productivity of knowledge-creating activities.*

In light of the substantial prior evidence of localized knowledge spillovers, finding support for these hypotheses in the subsequent empirical analysis would be relevant primarily because, as noted above, the context of the analysis minimizes the impact of (self-) selection into mobility, mobile agents were not knowledge-seeking, and mobility events were of a comparably short duration.

5.2.2 Cognitive Proximity, Social Proximity and Learning

Even though mobility allows agents to tap into new sources of relevant knowledge, it is not obvious that bridging geographic distance alone is sufficient to benefit from the opportunities that the new environment provides. Mutual understanding is an obvious first prerequisite of learning (Boschma, 2005; Huber, 2012). How well agents are able to understand information they newly encounter, and to evaluate its importance, depends on how closely it is related to their prior knowledge. The stronger this relation to prior knowledge is, the better their absorptive capacity for this new information tends to be, i.e. their "capacity to recognize, assimilate, and exploit" it (Cohen and Levinthal, 1989, p. 593). Cognitive proximity, i.e. the similarity of what they already know, can therefore be assumed as the most fundamental determinant of knowledge flows between individuals.

Cognitive proximity may also have a downside (Broekel and Boschma, 2012). Very similar prior knowledge compromises the subjective novelty of the newly accessed information for the agent. This will in turn limit her ability to derive useful insights from combining the new piece of knowledge with what she already knew before (Fleming, 2001; Nooteboom et al., 2007). In the context of mobile agents, this potential "trap" of excessive cognitive proximity in interactive learning may be a less salient concern, as mobility will often be motivated by the intention to access new sources of knowledge that differ from those involved in the agents' prior interaction. As will emerge below, we have little reason to worry about the problem of "excessive" cognitive proximity in the setting of our empirical analysis. We therefore hypothesize:

Hypothesis 3.a. *Cognitive proximity allows mobile agents to benefit from interactive learning in their post-mobility knowledge-creating activities.*

In addition to cognitive proximity, other factors condition the effectiveness of interactive learning. Various authors have emphasized the importance of social proximity stemming from personal ties, which may for instance be based on kinship, friendship, or shared prior workplace experience (e.g., Granovetter, 1985; Boschma, 2005; Broekel and Boschma, 2012). Social ties facilitate learning in a variety of ways. First, from the perspective of the learning agent, trust based on social ties enhances the perceived relevance and trustworthiness of received information. Second, social proximity may also be an important prerequisite for agents' willingness to share information with others. Prior work has suggested that knowledge often has "club good" characteristics, with bi-directional knowledge flows between agents interacting on a basis of (expected) reciprocity (Breschi and Lissoni, 2001). "Clubs" of informal knowledge trading can even encompass members of competing firms (Von Hippel, 1987; Schrader, 1991). As reciprocal knowledge sharing may be subject to free riding, authority relations and stronger control within a shared organizational context further enhance the potential for interactive learning (Boschma, 2005).

The relevance of social proximity in interactive learning is consistent with empirical evidence that localized patent citations are frequently based on labor mobility or social ties among inventors (Breschi and Lissoni, 2009). It may also help explain why competitive advantage in localized industry clusters is often limited to entrepreneurs who have previously worked for leading firms in the same industry (e.g., Wenting, 2008; Buenstorf and Klepper, 2009). Boschma (2005) proposes to further distinguish social proximity from institutional proximity, which derives from exposure to similar formal and informal institutions. The implied relevance of more "macroeconomic" factors for interactive learning resonates with empirical findings indicating the importance of ethnic ties for migrant inventors (Agrawal et al., 2006) and entrepreneurs (Alcácer and Chung, 2007). These considerations inform our final hypothesis:

Hypothesis 3.b. *Social and institutional proximity allow mobile agents to benefit from interactive learning in their post-mobility knowledge-creating activities.*

To some extent cognitive and social proximity are established in the course of interaction itself. However, a common cognitive basis may be required at the outset of interaction, as the interacting agents may otherwise be frustrated and give up in their endeavor to learn from their communication partner. Similarly, an initial lack of social proximity may compromise the quality of the interaction in irreparable ways. We accordingly focus on initial differences in cognitive and social proximity between interacting agents in our subsequent empirical analysis.

5.2.3 Empirical Identification Issues: Correlations in Proximity Dimensions and Self-Selection into Mobility

The extant empirical evidence on mobility and proximity effects is limited by two types of empirical identification issues. First, the various dimensions of proximity tend to be correlated and co-evolve in potentially complex ways (e.g., Broekel and Boschma, 2012; Huber, 2012; Crescenzi et al., 2016). In addition, empirical proximity measures often suffer from imprecise measurement. Accordingly, effects of individual types of proximity are difficult to separate using standard regression techniques. The second concern is that proximity is not given exogenously. Agents can and typically will shape their own proximity to others. Geographic proximity can be attained by moving closer to attractive interaction partners. Unless all prior mobility is observed, individual locations cannot therefore be assumed to be randomly distributed. Other dimensions of proximity may likewise be sought deliberately by the respective agents.

To deal with (self-) selection into mobility, a number of recent studies have studied effects of historical migration that was induced by "push" rather than "pull" factors, and where political risks and/or economic hardships left individuals little choice but to relocate. Several studies have analyzed the effects of Jewish emigration from Germany after 1933 on German and U.S. science and innovation (Waldinger, 2010, 2016; Moser et al., 2014). Drawing on more recent history, Borjas and Doran (2012, 2015b) have studied the emigration of mathematicians after the collapse of the Soviet Union. Analyzing such forced mobility events helps to isolate the effects of specific types of proximity. It also minimizes the potential bias of non-random selection into mobility. In what follows, we will adopt the same basic approach and exploit a facet of European 20th century history that, to the best of our knowledge, has so far escaped the attention of economists and geographers: the involuntary mobility of German experts as part of "intellectual reparations" schemes at the end of World War 2. Analyzing effects of involuntary mobility due to these programs allows us to overcome limitations of prior work on proximity and learning.

In an ideal experiment to test the above hypotheses, three groups of mobile people would be compared to an immobile control group. All groups would be as similar as possible initially and then be subject to alternative treatments. To single out the effects of cognitive and social/institutional proximity, one group of mobile agents would be matched to cognitively but not socially proximate partners, the second mobile group would be matched to partners who are only socially but not cognitively proximate, and the baseline effect of mobility would be controlled by matching the third mobile group to partners who are neither cognitively nor socially proximate. In the context of inventor productivity, this suggests that before the treatment, members of all groups should have been similarly productive. Subsequently, three groups should be exposed to a mobility event. One of the groups should be treated for cognitive proximity, i.e. members of this group would be matched with partners from the inventors' field of expertise but with different social backgrounds. The other group would be treated for social/institutional proximity, i.e. their partners should be active in fields outside the inventors' expertise but share their social background. Finally, partners of inventors in the third group should be different both in their field of expertise and in their social/institutional background. In this way, both the effect of mere exposure to new partners of interaction and the effects of cognitive and social/institutional proximity could be isolated. In what follows, we will describe and analyze a historical context very similar to this ideal experiment.

5.3 Post-WW2 Intellectual Reparations and the BIOS Program

German science and technology were highly developed prior to WW2. Before the Nazi government dismissed and in many cases killed Jewish and "politically unreliable" scientists, German universities were world leaders in a variety of science and engineering disciplines (Waldinger, 2016). Despite the subsequent brain drain, Nazi war efforts provided the remaining German scientists with good working conditions in fields that were deemed of pivotal military importance. Industrial research and development likewise benefited from a long-standing commitment to research (cf. Murmann, 2003, for the chemical industry) and from war preparations. For instance, the Nazi government's objective to decrease imports boosted research efforts in the field of synthetic materials and fuels. At the same time, Nazi policies favored some fields of research over others. In 1937, the Imperial Research Council (*Reichsforschungsrat*) was established to centrally plan basic and applied research. The Council prioritized research activities relevant to weapons production; less directly war-relevant activities were de-emphasized (Macrakis, 1993; Renneberg and Walker, 1994).

Already in 1944, the Allied forces initiated several programs to get hold of German scientific and technological knowledge. These programs quickly evolved to grow increasingly sizable. Originally, the U.S. and U.K. governments hoped to acquire useful German knowledge for military purposes, which was justified with the need for advanced technology to win the war against Japan. Soon, however, military considerations gave way to an overt willingness to extract "intellectual reparations" (Gimbel, 1990b) from Germany to support the competitiveness of U.S. and U.K. industries. German production sites and R&D facilities of interest were identified, secured and systematically searched for valuable information. Many of the captured documents were not self-explanatory, and German experts had to be found and interrogated to make them intelligible.

In the aftermath of WW2, German scientists, engineers and technicians were held captive in special camps in the respective occupation zones in Germany. In the emerging cold war, their detention also helped the U.S. and U.K. governments to keep German knowledge from falling into Soviet hands. Under CIOS, the "Combined Intelligence Objectives Subcommittee", U.S. and U.K. agencies exchanged information about captive researchers as well as potential targets for detention. Captives were also exchanged between both partners (Gimbel, 1990b; Jacobsen, 2014). "Whether they liked it or not" (Gimbel, 1990b), numerous German experts whose knowledge promised to be useful were taken from Germany to reveal their expertise in the Allied countries. Wernher von Braun's research group, which was flown to the U.S. right after the war had ended, is only the most prominent example (Lasby, 1971; Jacobsen, 2014; cf. also Von Schirach, 2012 for the detention of leading German nuclear physicists in the U.K.). The military documents keeping record of these programs were only recently and gradually declassified. To our best knowledge, the present study is the first quantitative analysis conducted on the basis of these data.

In this paper, we focus on the "BIOS" program ("British Intelligence Objectives Sub-Committee") set up by the U.K. government to extract information from Germans knowledgeable in various fields of science and engineering. These experts were taken to the U.K. where they were held captive in a detention center. Internment came as a surprise to most experts, who had been told they would be short-term "guests of the British Empire". Instead, they spent weeks or even months in a camp secured by barbed wire. Surviving notes suggest that even though the detainees did not suffer from physical hardships - most likely their living conditions were better than they would have been in Germany - they did not appreciate being treated like prisoners. Other causes of discontent included uncertainty as to when they would be able to return to Germany, and also the boredom they experienced in the camp.

The detained experts spent most of their time in the detention center, only to be questioned from time to time by British officials or company representatives, which could involve being taken to other parts of the U.K. on the request of companies located there. Some had pre-existing contacts to British firms, which they believed they could renew during their stay in Britain. However, this was mostly prohibited by British officials, who fully controlled the schedule of meetings and interrogations (Gimbel, 1990a). Expert talks between the Germans and employees of U.K. firms thus established new contacts. In the meetings with their British counterparts, the Germans talked to experts from their fields trying to tap into their expertise to solve practical problems. Thus, even though the rationale of the detention was to "exploit" (Gimbel, 1990b) the German expertise, the detained Germans also learned about technological interests, approaches and problems on the British side. Such bi-directional flow of knowledge actually was a concern of the British officials involved with the program (ibid.). For instance, in personal notes on his internment under the BIOS scheme, Degussa engineer Dr. Ernst Baerwind lists details about his employer's U.K.-based competitors, other U.K. firms and their activities, the individuals he had talked to, and an analysis of questions they had asked with guesses as to what these firms' research interests might be. He also mentions that many detainees knew why they were detained because they were narrowly specialized or were only interrogated about very specific projects (Gimbel, 1990a).

To deal with their idleness between interrogations, detainees engaged in the mutual exchange of ideas and knowledge. They organized regular lectures and seminars where each would provide insights into their own field of expertise. Eyewitness reports indicate that this teaching had more than just entertainment value. For example, in Dr. Baerwind's words: "[Prof. Schwenkhagen's] series of lectures on 'nuclear physics, nuclear fission and the atomic bomb' and his 'colloquium on electrical engineering' constitute one of the most effective intellectual gains of the detention in Wimbledon" (Gimbel, 1990a, our translation). Dr. Baerwind characterizes the overall situation as "a wondrous combination of recreation center, prison and intellectual brothel" (ibid.).

Our analysis in this paper will focus on the effects that the BIOS program had on the subsequent patenting activities of the German experts. For several reasons, the BIOS program is a highly suitable empirical context for our study. First, as noted above, detention was involuntary and came as a surprise to the German experts. Second, as the detainees could not choose their interrogation partners, nor the other Germans with whom they would end up spending their time in the detention centers, they were unable to self-select into specific contacts. Third, effects of BIOS on the detained German experts were not intended by the British governments, and experts were not selected on the basis of their expected ability to learn. To the contrary, BIOS was to help U.K. firms understand how their German competitors approached specific scientific and technological problems (which could be of a rather mundane nature), and U.K. officials worried about potential leakage of knowledge to the Germans. Detainees were selected because of their expertise in particular fields of technology, not because of their general intellectual abilities or potential to learn. Because of these characteristics, BIOS can be regarded a natural experiment treating a group of German scientists and engineers who are otherwise comparable to non-treated experts with similar observable characteristics. On average, detention lasted about six weeks. Accordingly, exposure to the treatment was unlikely to attenuate initial differences in cognitive and social/institutional proximity.

BIOS differs from the hypothetical ideal experiment sketched above in that German experts were subject to a double treatment. However, BIOS was unique because individual contacts were unusually dissimilar in their extent of cognitive as opposed to social and institutional proximity. When questioned by British officials and industry experts, Germans interacted with experts from their own field of specialization, i.e. in a context of high cognitive proximity. These experts represented a country that had been a war enemy until shortly before, and whose government had forcibly taken them to the detention center. In addition, the German experts had been exposed to twelve years of extremely antagonistic propaganda against foreign countries, which they had neither openly opposed nor escaped by emigration. They did not know how long the detention would last and what fate awaited them afterwards. All this suggests extremely low degrees of social and institutional proximity between German and English experts.

The opposite pattern (low degree of cognitive proximity but high degree of social/institutional proximity) characterized the interaction among the German experts. Cognitive proximity was generally low as each detainee was an expert in their own field. There is no evidence that detained experts had exactly the same specialization. For the U.K. authorities, such a duplication of expertise would not have made sense, as it would have increased the risk of knowledge leaking to Germany. In contrast, the degree of social and institutional proximity among German experts was presumably high. Most of them were highly educated men (at least 59 per cent of the experts in our sample held doctoral degrees), which is suggestive of similar social backgrounds given the exclusive character of higher education before WW2. They had kept or newly attained research positions during the Nazi years, when many careers were aborted for ideological reasons, which further indicates a basic similarity in attitudes and behaviors. Now they found themselves detained in a foreign country and facing the same uncertain post-war fate. In addition, except for the times when they were interrogated, the Germans spent most of the time together with the others who were detained at the same time. This provided them with ample opportunities to talk to and learn from each other, and to establish social ties.

Accordingly, even though we only have a single treatment group, the conditions of the hypothetical ideal experiment are approximated because the roles of cognitive and social/institutional proximity in the effects of mobility can clearly be separated. The most relevant limitation of our empirical context is the lack of a treatment group that experienced neither form of proximity. This prevents us from separating the proximity effects from the "baseline" effect of mobility, which should be taken into account in the interpretation of our findings.

5.4 Data

Our primary data to study effects of the BIOS program are lists of German scientists and engineers who were taken to Britain between October 1946 and August 1947. These lists were made publicly available by the U.K. Ministry of Supply in 2006. They encompass three distinct projects, "BIOS", the "Darwin Panel Scheme" and the "DCOS Scheme" ("Deputy Chiefs of Staff's Scheme"). We focus on BIOS, which was the most sizable of the three programs. BIOS was special in that it brought German experts to the U.K. for limited periods of time, whereas the Darwin Panel Scheme and the DCOS Scheme aimed at getting Germans employed at U.K. firms.

After retrieving the experts' names and the duration of their stay from the lists, we searched for their names on patents in DEPATISnet, the online database of the German patent office. We counted 249 experts who stayed in the U.K. for at least one week (mean: 6 weeks). 169 were involved in patenting activities. 40 detainee names matched with multiple inventors. As we could not clearly distinguish which of the matched inventors is the one on the BIOS list, we exclude them from the sample. Of the 129 experts left, we found 74 to have patenting activities both before and after the treatment year (1947). Between them, they are listed as inventors on 4,206 unique patent documents. We examined all documents manually to identify the country of residence of the experts as well as their applicants and co-inventors. In addition we tracked all foreign citations to these patents using the PATSTAT database (2014 Autumn Release), matching our list to PATSTAT via patent publication numbers.[1]

A control group is required to estimate the effects that the treatment had on the German experts. For our main analysis, we decided to turn to comparable Swiss inventors as our controls.[2] Swiss inventors provide a suitable control group for several reasons. As opposed to German inventors who are not listed as subject to the BIOS program (and would thus also qualify as controls for our analysis),

[1]Some of the patents retrieved from DEPATISnet could not be found in PATSTAT. Other documents were not digitally available in DEPATISnet. The 4,206 documents mentioned are priority patents (of DOCDB patent families) which could be found in both databases. Originally we obtained 5,510 patents from DEPATISnet (including all patent family members). Furthermore, citation reports were only available for patents published at the German patent office. This limited us in the possibilities for citation analyses.

[2]A Swiss control group is also used by Biasi and Moser (2017) for a comparison with German books published before World War 2.

for Swiss inventors we can rule out that they were affected by one of the other similar programs that were set up by the Allied countries. In addition, Switzerland directly borders on Germany and is relatively similar in terms of culture and (at the time) industrial structure. It was neutral in World War 2, which should make it a better match than any of the Allied countries.

A potential concern about our Swiss control group is that the patenting activities of the treated German inventors in and after World War 2 might be affected by factors unrelated to the treatment in the BIOS program, which might then be wrongly ascribed to the treatment. To address this concern, we constructed a second control group that consists of German inventors comparable to the treated ones. While we have no information that these control inventors were subject to BIOS or similar programs, we cannot exclude this possibility, which is why we consider the Swiss control group as superior. We nonetheless conducted and report the same empirical analyses for both control groups. We report and discuss results for analyses using the control group of Swiss inventors in the following. Results for the German control group are very similar; they can be found in the Appendix.

In constructing our Swiss control group, for each German patentee we identified the most similar Swiss "twin" based on their patenting activities prior to 1947. We picked twins as follows: First we searched for Swiss inventors active in the same patent classes as the German inventors. At the most detailed IPC level, we found potential matches for 43 of the German experts. We went through the list of potential matches and compared inventors' patent output before 1947, selecting the most similar one for each German. We only included Swiss inventors who were active after 1947 which ensures a reasonable comparison in the post-1947 period. For the remaining 31 Germans we repeated the same procedure at the four-digit IPC level. For the Swiss control group, we then repeated the patent scanning procedure we had undertaken for the Germans.

For six German inventors no appropriate twin could be found, leading to 68 Swiss inventors on the list (the respective German inventors were dropped). Not for all patents all required bibliographic information was accessible. We decided to exclude all patents lacking full information. This further reduced our sample by 10 German inventors (and their Swiss counterparts) who had no patents left in either the pre- or post-1947 period. Accordingly, the final sample includes 58 German and 58 Swiss inventors. All of them are male.

Descriptive statistics of our sample are presented in Table 5.1. Pairwise correlations of our main explanatory variables are presented in Table 5.2. In addition to the number of patents filed before and after 1947, Table 5.1 also shows the incidence of U.K. affiliations (which we set to 1 if an inventor is listed with a U.K. address), as well as the average number of U.K. applicants and U.K. co-inventors. Also shown are U.S. affiliations, applicants and co-inventors, which we will use to control for overall internationalization. The table shows that the Swiss control group matches the BIOS sample well, as there are no significant differences between the average statistics before 1947 (except for U.S. applicants, where there is some German-U.S. interaction before 1947) and there are no significant differences between the time spans during which Germans and Swiss were active.

In contrast, there are significant differences between the two groups after 1947. The number of post-treatment patents is significantly higher for German inventors, consistent with Hypothesis 2. Twelve per cent of the German inventors stated their residency to be in the U.K. after 1947. Here, the difference between the German and the Swiss group also becomes significant after the treatment. The number of U.K. applicants likewise increases for Germans and becomes significantly different from that of Swiss inventors. We also observe an increase in the average number of co-inventors from the U.K. (from 0.02 to 0.12), but the difference between treatment and control group is not significant.

5.5 Empirical Analysis

Using the patents filed by detained German inventors and Swiss controls, we first study whether observable post-treatment outcomes suggest traces of the U.K. detention experience (as predicted by Hypothesis 1). We then compare the development of patenting output over time for the two groups (Hypothesis 2). Finally, we begin to disentangle potential effects of cognitive and social proximity (Hypotheses 3.a and 3.b).

Table 5.1: Descriptive Statistics (Swiss control group)

	full sample	Germans	Swiss	
n	116	58	58	
all patents pre	1658	909	749	
all patents post	2933	2427	506	
average (median in breakets)				p-value (mean difference)
patents pre	14.29 (8)	15.67 (8)	12.91 (8)	0.42
patents post	25.28 (6)	41.84 (11)	8.72 (4)	0.02
year first patent filed	1928.34 (1929)	1929.84 (1931)	1926.84 (1927)	0.09
years active	31.53 (32)	31.19 (32)	31.88 (33)	0.74
UK affiliation pre	0.01 (0)	0.02 (0)	0 (0)	0.32
UK affiliation post	0.07 (0)	0.12 (0)	0.02 (0)	0.03
UK applicant pre	0 (0)	0 (0)	0 (0)	
UK applicant post	0.13 (0)	0.26 (0)	0 (0)	0.01
UK co-inventor pre	0.01 (0)	0.02 (0)	0 (0)	0.32
UK co-inventor post	0.06 (0)	0.12 (0)	0 (0)	0.11
US affiliation pre	0.01 (0)	0.02 (0)	0 (0)	0.32
US affiliation post	0.02 (0)	0.02 (0)	0.02 (0)	1
US applicant pre	0.09 (0)	0.17 (0)	0 (0)	0
US applicant post	0.02 (0)	0.02 (0)	0.02 (0)	1
US co-inventor pre	0 (0)	0 (0)	0 (0)	
US co-inventor post	0.06 (0)	0.07 (0)	0.05 (0)	0.82

Note: Descriptive statistics comparing the group of treated Germans and the Swiss control group. Averages are arithmetic means. U.K./U.S. affiliation pre/post are dummy variables that take the value 1 if there is at least one patent before/after 1947 on which the inventor is listed as having a U.K./U.S. address. U.K./U.S. applicant pre/post and U.K./U.S. co-inventor pre/post count the number of applicants/co-inventors from the U.K./U.S. listed on the inventor's patents before/after 1947.

Table 5.2: Correlations

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
treat (1)	1	0.07	0.22	0.13	0.26	-0.03	0.16	0.14
patents pre (2)		1	0.29	-0.01	-0.01	0.3	-0.25	0
patents post (3)			1	-0.03	0.13	0.13	0.07	0.84
UK interaction pre (4)				1	0.18	0.14	0.01	-0.03
UK interaction post (5)					1	-0.04	0.15	-0.01
years active (6)						1	-0.79	0.06
year first patent filed (7)							1	0.08
patents in new IPC (8)								1

Note: Pairwise correlations of main explanatory variables.

To trace potential effects of the detention treatment on the patenting activities of German inventors, a simple univariate difference-in-differences calculation of three observable outcomes is presented first (Table 5.3). "U.K. address" measures whether or not an inventor moved his residency to the U.K. "Total number of U.K. co-inventors" measures the number of co-inventors from the U.K. listed for the inventors in our two groups, whereas "total number of U.K. applicants" does the same for applicants located in the U.K.. We focus on the means of these three variables and how they differ between the treatment and control groups. The diff-in-diff estimator shows the difference of this difference between the two time periods (before and after the treatment in 1947).

To test whether the difference in the differences of the means deviates from zero, we estimated their distribution by random resampling. Quantiles cutting zero received by this bootstrapping are shown in the last column of Table 5.3. They point to a low likelihood of obtaining similar results by chance. Furthermore, only two of our German experts seem to have shifted all their activities to the U.K.. Others seem to have remained in contact with German inventors and applicants while also moving some activity (residency and/or co-inventors/applicants) to the U.K. All this is in line with Hypothesis 1, which predicted that migrating inventors draw upon new opportunities for interactive learning in their subsequent knowledge-creating activities. Our findings also show that, as intended by the U.K. government, detention was a short term affair, and mostly did not lead to permanent relocation.

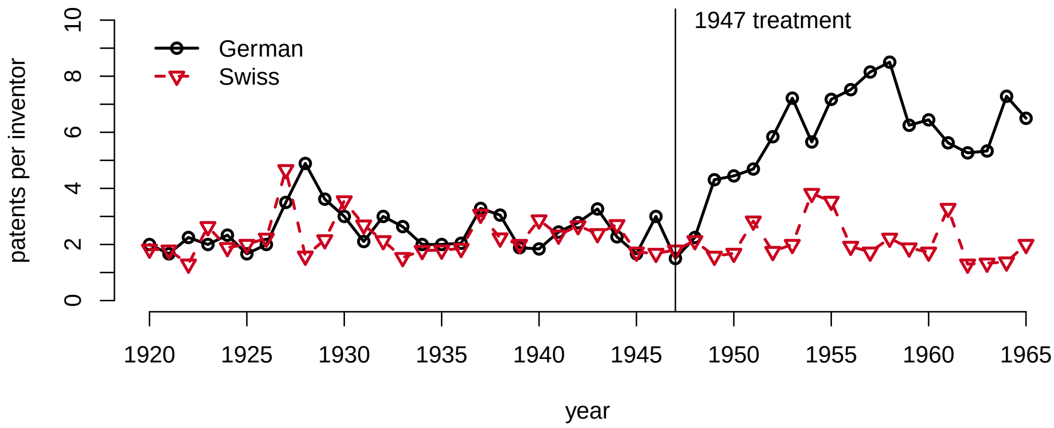
Table 5.3: U.K. Interaction - Diff-In-Diff Estimates

number of inventors	Germans pre	Germans post	Swiss pre	Swiss post	diff-in-diff estimator	quantile cutting zero*
UK address	1	7	0	1	0.09	0.04
UK co-inventors	1	4	0	0	0.05	0.12
(UK co-inventors total)	1	7	0	0	0.1	0.09
UK applicants	0	9	0	0	0.16	0
(UK applicants total)	0	15	0	0	0.26	0
any kind of UK interaction	2	10	0	1	0.14	0.01

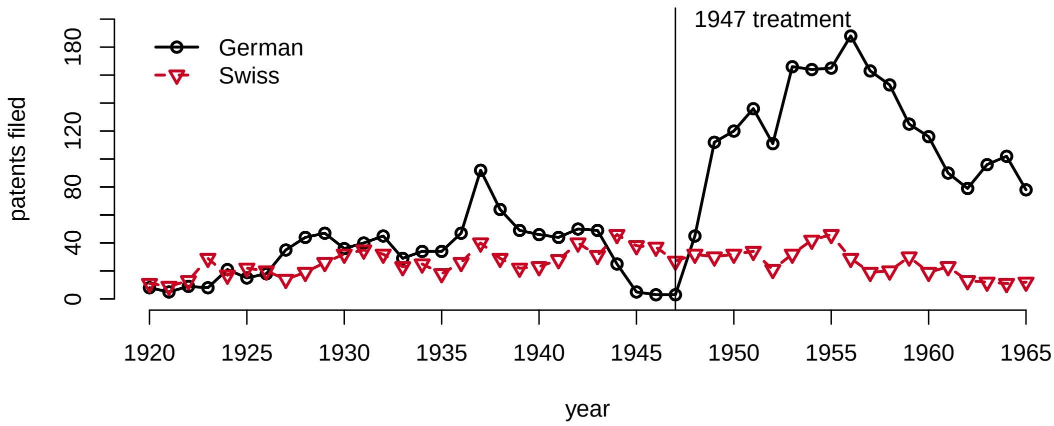
Note: * Bootstrapped with 1000 iterations. Calculation estimating whether the difference in differences of the means of UK-interaction variables between treatment group and Swiss control group deviates from zero. "U.K. address" measures whether or not an inventor moved his residency to the U.K. "U.K. co-inventors" and "U.K. applicants" measures whether or not an inventor has co-inventors/applicants from the U.K.. Total number of U.K. co-inventors measures the number of co-inventors from the U.K. listed for the inventors in the two groups. Total number of U.K. applicants does the same for applicants located in the U.K.. "Any kind of U.K. interaction" measures whether or not an inventor had U.K. affiliation and/or applicants and/or co-inventors.

Next, individual counts of patent applications are studied to test Hypothesis 2 predicting productivity-enhancing effects of inventor migration. We employ a multivariate diff-in-diff framework that identifies the treatment effect by estimating whether the difference between the number of pre- and post-1947 patent applications differs between members of the treatment and control groups. Suitability of the diff-in-diff framework is suggested by Figures 5.1a and 5.1b, which graph the (average) number of patent applications over time for both groups. Pre-1947 patent applications develop in a very similar way in Germany and Switzerland, i.e. the common trends assumption is satisfied. Since patent counts are non-negative integers, we use a negative binomial model. Pooling the data of both time periods leads to a total of 232 observations (116 pre and 116 post).

To obtain the treatment effect, in Model 1 we include dummy variables for the post-treatment period (post1947, taking the value 1 for post 1947 activities) and for the treatment group (German, taking the value 1 for the treated Germans). The interaction term takes the value 1 for post-1947 observations belonging to a German inventor. Alternatively, in Model 2 the time period under observation is



(a) Average Number of Patents Filed per (Patenting) Inventor



(b) Number of Patents Filed

Figure 5.1: Patents Filed per Year and Group

subdivided into ten time categories (eight five-year intervals from 1922 to 1961 plus the time periods before and after these intervals).[3] In Model 3, we include a full set of inventor-specific time-trend effects.

$$y_{ij} \sim \alpha + treat * post1947 + treat + post1947 + controls + e_{ij} \tag{5.1}$$

To control for age effects, we further include a variable for the year the first patent was filed. Industry-specific differences in patent activities, which might further bias our results, are controlled with IPC level (A-H) dummies.

Regression results are presented in Table 5.4. The key finding is that in all three models the interaction term *treat*post1947* is positive and highly significant, with coefficient estimates implying an increase in patent output of about 180-250 per cent for the treated inventors. In line with Hypothesis 2, German experts detained in the BIOS program experienced a much stronger increase in their post-1947 patenting than their Swiss counterparts. We also obtain the expected patterns for the age control. In Appendix Table B.6 we report estimation results for a subset excluding outliers. We excluded the four German inventors who had more than 180 patents (equal to the mean plus two times the standard deviation). In another model, we include a further dummy to control for those inventors with observable U.K. collaborations or U.K. addresses (Appendix Table B.7). Results are robust to both these modifications.

Hypotheses 3.a and 3.b make predictions about the effects of cognitive and social/institutional proximity on interactive learning. As noted above, our empirical context allows us to test these hypotheses separately. Based on Hypothesis 3.a, we expect that the German experts acquired new knowledge in their interaction with British experts from their field, which could then explain the rise in productivity observed in Models 1-3 above. To test this prediction, we employ measures of direct involvement with U.K. partners (shares of U.K. applicants and co-inventors) in the set of patent applications studied above and study how these measures are related to the individual increase in

[3] In model 1, we thus have two observations per inventor (pre 1947 and post 1947), leading to a total of 232 observations. In models 2 and 3, we have one observation per inventor per time period, which leads to a total of 1,160 observations.

Table 5.4: Regression Results on the Productivity of Inventors

	Dependent variable:		
	number of patents applied (in period t)		
	(1)	(2)	(3)
post1947*treat	1.249***	1.236***	1.031***
	(0.377)	(0.273)	(0.2)
post1947	−0.351**		
	(0.166)		
treat	0.159	0.169	0.741**
	(0.23)	(0.177)	(0.322)
year first patent filed	−0.018	−0.040***	−0.03***
	(0.013)	(0.008)	(0.000)
(Intercept)	37.005	74.386***	55.13***
	(24.413)	(16.083)	(14.91)
IPC dummmies	Yes	Yes	Yes
period effects	No	Yes	Yes
individual time effects	No	No	Yes
Observations	232	1,160	1,160
Log Likelihood	−862.892	−2,238.666	−2,259.88
Akaike Inf. Crit.	1,751.784	4,519.333	4,547.759

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from negative binomial regression models. Robust clustered (on inventor level) standard errors in parentheses. Treatment dummy denotes detention in the BIOS program. Control group includes comparable Swiss inventors. IPC dummies at first letter level (A-H). Pre-/post-treatment observations are pooled in Model 1. Models 2 and 3 distinguish eight 5-year periods as well as the years before 1922/after 1961. Model 3 includes a full set of inventor-specific time-trends.

patenting output after 1947. We also construct analogous measures of involvement with U.S. partners to have a benchmark against which the results for the links to the U.K. can be interpreted. OLS is used for estimation because the increase (ratio of post- vs. pre-1947 patents) is continuous.

In Model 1 (Table 5.5), we first reproduce the main finding from above, i.e. that the German experts experienced a stronger increase in patent output than the members of the Swiss control group. Model 2 adds the shares of U.K. and U.S. applicants in the post-1947 period to the model. The coefficient estimate for the U.K. measure is positive (but not significantly different from zero), whereas the one for the U.S. variable is negative (and likewise insignificant). In Model 3, shares of U.K. and U.S. co-inventors instead of applicants are used as proxies of international interaction. Here we obtain an even more sizable coefficient for the U.K. variable, which is marginally significant at the 10 per cent level, indicating that inventors who had larger fractions of post-war patents with U.K. co-inventors experienced stronger increases in their patent output. As predicted by Hypothesis 3.a, interaction with U.K. co-inventors appears to have helped the post-WW2 productivity of the German experts. In contrast, no evidence suggestive of such a relationship is obtained for the interaction with U.S. co-inventors. Again, these findings are robust to excluding outliers in terms of patent applications (results are presented in Appendix Table B.8).

Ideally, we would further analyze the effects of knowledge flows indicated by backward citations to U.K. patents as a measure of using British technology. Unfortunately we lack consistent information about patent documents from patent offices outside Germany (including the Swiss office). Search reports from other patent offices were not accessible, neither in PATSTAT nor directly at the national patent offices' websites. Since Swiss inventors filed their patents mostly at the Swiss patent office, we can only look at the citations of the German experts. In unreported analyses (available upon request) we looked at the role of citations to U.K. patents in this sample. Consistent with Hypothesis 3.a, the share of U.K. citations was directly related to the productivity of inventors.

As a final piece of evidence regarding Hypothesis 3.a, we analyzed the backward citations contained in the post-1947 patents filed by the German experts (see Table 5.6). As the German experts were interrogated about their fields of expertise, which is reflected in their pre-1947 patents, it is plausible

Table 5.5: Regression Results Explaining Post 1947 Patent Outputs

	Dependent variable:			
	percentage change in patenting activity			
	(1)	(2)	(3)	(4)
German (treat)	5.617**	5.206*	5.196*	5.014*
	(2.760)	(2.960)	(2.800)	(2.774)
year first patent filed	0.110**	0.106**	0.098*	0.097*
	(0.049)	(0.052)	(0.050)	(0.051)
nbr patents pre 1947	−0.134**	−0.128*	−0.118*	−0.131*
	(0.068)	(0.068)	(0.067)	(0.073)
UK applicants post 1947 (share)		8.547		
		(10.376)		
US applicants post 1947 (share)		−10.729		
		(6.629)		
UK co-inv. post 1947 (share)			22.794*	22.662*
			(12.627)	(12.222)
US co-inv. post 1947 (share)			−3.399	−3.202
			(3.360)	(3.302)
patents in new IPC (share)				1.445
				(1.436)
(Intercept)	−219.083**	−210.631**	−193.948**	−193.877**
	(94.625)	(101.406)	(97.336)	(98.176)
IPC dummmies	Yes	Yes	Yes	Yes
Observations	116	116	116	116
R^2	0.239	0.252	0.270	0.272
Adjusted R^2	0.159	0.157	0.177	0.171
Residual Std. Error	8.951 (df = 104)	8.959 (df = 102)	8.854 (df = 102)	8.885 (df = 101)
F Statistic	2.970*** (df = 11; 104)	2.650*** (df = 13; 102)	2.899*** (df = 13; 102)	2.694*** (df = 14; 101)

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from OLS regression models, (robust) standard errors in parentheses. Patenting activities with U.K./U.S. applicants/co-inventors are measured through their shares among overall patent applications per inventor. "Patents in new IPC" measures the share of applications per inventor that fall into subjectively new IPC classes.

Table 5.6: Citations of "Old" and "New" IPC Patents

	patents in:		(p-value)
mean citations to	new IPC	old IPC	mean difference
U.K. patents	0.09	0.18	0.01
U.S. patents	0.48	0.54	0.52
German patents	1.09	1.11	0.87

Note: Average number of backward citations found in post-1947 patent applications filed by treated German inventors. New (old) IPC refers to patents that (do not) have at least one subjectively new IPC class.

that learning from the interaction should show up in those new patents that relate to the same field of expertise. In line with this conjecture, we find that the average number of citations to patents from the U.K. is about twice as large for patents that share at least one IPC class with the pre-1947 patents by the same inventor than it is for patents that entirely fall into new IPC classes (from the inventor's perspective). In contrast, no differences between "old" and "new" patents are obtained as regards the (more frequent) citation of German or U.S. patents.

In Hypothesis 3.b, we predicted that social and institutional proximity supports interactive learning. In our context, this suggests that the German experts interned in the U.K. benefited from interactions with each other. To see whether the increase in productivity was driven by interactions among the German experts during their detention, we searched for co-inventions and mutual patent citations. No co-inventorship was found between any of our experts. Nor did the IPC classes in which they were active systematically converge after World War 2. As regards mutual patent citations, we found one citation from a pre-1947 patent to another patent from the same period, 10 citations from the post-1947 period to the pre-1947 period, and 26 citations from the post-1947 period to a patent from the same period, but all of these citations were identified as self-citations. Accordingly, there is no evidence of any relevant knowledge transfer between the German experts who stayed together in the U.K..

As another aspect of testing Hypothesis 3.b, we finally explore the role of broadened technological scopes of patent portfolios in explaining post-war increases in patent output (Model 4 in Table 5.5).

Specifically, we include the share of patents per inventor in subjectively new (four-digit) IPC classes as an additional explanatory variable. The idea underlying this variable is that even though they did not co-invent nor cite each others' patents, the detained experts may nonetheless have gained new insights from their peers that subsequently allowed them to venture into new fields of technology. Another attractive feature of this test is that it allows for effects of non-patenting detainees on their patenting peers, thus broadening the range of captured interactions. The coefficient obtained for this measure of patents in new IPC classes is small and far from attaining statistical significance at conventional levels. Increases in post-war patenting were not related to entering into new fields of technology.

Joint with the absence of co-inventions and citations among the German experts, this finding on IPC classes leads us to conclude that Hypothesis 3.b is not supported by our data. Over the 47 weeks of our period of observation, on average 6.5 researchers from our sample were detained together at the same time. There were accordingly opportunities for interactive learning between the Germans, who after all spent more time together than they did during the interrogations by U.K. experts. Nonetheless, the interaction within the group of Germans did not result in observable effects on their inventive activity.

We thus conclude that at least in our empirical setting, cognitive proximity is more important than social and institutional proximity to account for the productivity-enhancing effects of inventor migration and interactive learning.

5.6 Concluding Remarks

Exploiting a natural experiment conducted in the aftermath of WW2, we contribute to the literature on proximity and knowledge diffusion by providing new evidence on the antecedents of interactive learning. Our unique sample of German inventors who were taken to the U.K. for interrogation in 1946/47 enables us to distinguish between two simultaneous treatments. German experts were questioned by British officials and industry experts from their field of expertise. Underlying these encounters was a high degree of cognitive proximity, but a low degree of social and institutional proximity. In addition, the detained German experts interacted among themselves. In this interaction, the level of social and institutional proximity was high, whereas cognitive proximity was low.

In line with prior literature, we find support for our first two hypotheses predicting that mobile agents exploit the opportunities for interactive learning that mobility provides them with, which then leads to an increased inventive productivity. Our data show that their stays in the U.K. led to network extensions focused on the U.K. for our German inventors, as compared to the Swiss counterparts in the control group. We also found the detention treatment to have a positive impact on the German inventors' productivity, as indicated by patent counts. These results showed robust when an alternative control group of matched German inventors was employed.

We expected cognitive proximity as well as social and institutional proximity to be relevant for the mobility-induced increase in productivity. The empirical evidence is consistent with a substantial effect of cognitive proximity. That the German experts appear to have learned from their interactions with British officials and firm representatives is noteworthy also because this is the opposite of what the U.K. government wanted to achieve. The clearly stated objective of the BIOS program was to drain knowledge from the Germans, and not to teach them or trade knowledge with them. Our study indicates that such one-way "exploitation" of knowledge may be extremely difficult to achieve.

In contrast, our results do not provide evidence that social and institutional proximity played an equally important role as cognitive proximity. We could not find any kind of post-treatment links among the German experts who were interned together. This is all the more surprising since the rare historical literature on the subject suggests that the interned Germans spent most of their time together and even gave and attended lectures about their respective work.

Even though the BIOS program provided an excellent empirical context for our study, our analysis is not without limitations. Conceptually, our empirical context does not allow us to clearly distinguish social from institutional proximity. Regarding the former, we do not observe intimate and long-standing social ties that may underlie the importance of social proximity found in other settings. Empirically, the sample of experts we could analyze was relatively small, and not all of them experienced the detention treatment at the exact same time. In addition to incomplete access to the lists of BIOS subjects, the sample size was further reduced because - due to lacking additional information - some detainees could not be disambiguated with sufficiently high reliability. Also, our analysis was limited to patent data, and historical patent citations could only be obtained for a subset of all patents. Finally, as noted above, our data do not allow us to isolate the "baseline" effect of mobility from the effect of cognitive proximity. Some of these limitations may be overcome by future work. We are convinced that there is still a lot of potential in the analysis of post-WW2 knowledge exploitation programs for further research on knowledge production and innovation.

Chapter 6

Conclusion

The studies presented in this dissertation all contribute to the literature on the economics of knowledge creation and diffusion. They use unique datasets and contemporary methods to close some of the gaps identified in the research on how new knowledge is created, and especially what role the individual plays in this process. Three of these studies focus on researchers active in academia, and on influences on their careers, which in turn affect the ways in which new knowledge is produced and spread. The fourth study uses historic patent data in the context of a post-WW2 natural experiment, which allows for some general insights about the relevance of different types of proximity.

All four studies use novel secondary data sets to come to their conclusions. A number of different data sources are used to collect information about individuals' dissertations and *Habilitationen*, scientific publications, patents, labor market histories and some other person-specific data. A lot of work went into making these datasets as representative as possible. The econometric methods used range from relatively simple OLS models to poisson models (negative binomial as well as poisson pseudo maximum likelihood models), probit and multinomial logit models as well as complementary log-log hazard models. One study remains purely descriptive, and instead focuses on properly depicting networks. The following results of the four studies all add to the understanding of knowledge production processes, and of the relevance that mobility along certain kinds of distances plays regarding the individual researcher.

The study in chapter 2 tries to answer the question whether or not entrepreneurial behavior, which universities claim to promote in and demand from their professors is actually rewarded. In it, we utilize the German reunification and the subsequent restructuring of the East German academic system as a natural experiment. We show that a demand shock on the academic job market can be observed in all three disciplines in our study (physics, economics and business administration), as shown through higher hiring chances for junior researchers who received a *Habilitation* degree shortly before or after reunification. This comes as somewhat of a surprise, because the demand shock was expected to be much stronger in the social sciences than in the natural sciences, but instead we find a substantial shock in physics and economics, and only a weak shock in business administration (this can partially be explained by much higher overall hiring chances of graduates in business administration, though). We then go on to argue that the newly opened positions in the East can be seen as an opportunity for researchers to take part in shaping a research institution from the very beginning. We indeed find that, if there is a difference at all, it seems to be the more productive researchers who take the chance of going east. However, this taking of a chance does not seem to be rewarded. While there are no effects of going east on the researchers' productivity, further hiring chances for economists who went east strongly decrease. We interpret this as researchers' entrepreneurial behavior not being rewarded on the German academic job market.

In the study in chapter 3, I construct a sample of highly qualified junior researchers in physics to get a better idea of high voluntary thematic mobility may influence researchers' acceptance within the scientific community. I rely on data on physicists who received Emmy Noether research grants, which are highly reputed and rather generous. I argue that for these researchers, thematic mobility is more likely to be of a voluntary nature than for others. I then construct two different measures for thematic mobility, one relying on the comparison of keywords and one relying on the comparison of abstract texts. I additionally use two different measures for the researchers' success, one being the citation count, and the other being the probability to receive an award, which might be better in showing the thematically mobile researcher's acceptance in the establishment. I can find neither positive nor negative relationships between thematic mobility and either success measure. I interpret this as a sign for these highly qualified researchers being good at estimating whether or not being thematically mobile pays off, and then choosing whichever path they deem more likely to lead to success. Due to the design of the study, I however cannot make any causal inferences, and I highly recommend further research in this direction.

In chapter 4, I present a study in which I look at the prevalence of scientific families in German business studies. I show that in WK ORG, a subsection of the German Academic Association for Business Administration (*Verband der Hochschullehrer für Betriebswirtschaft*, VHB), one professor was especially successful in placing his advisees as professors. Since this is a purely descriptive study, I can only use previous literature to make some guesses as to how he was able to do so. I expect a mixture of the passing down of tacit knowledge through the generations and network effects to be responsible for this disproportionate presence of one professor's scientific offspring in today's Business Research community.

Finally, in the study in chapter 5, we tackle the importance of different proximity types by looking at another natural experiment. We use the context of German researchers who were brought to the U.K. after the end of the second World War to be questioned by U.K. company representatives, and later brought back to Germany, to show that cognitive proximity plays a bigger role in knowledge transfers than social proximity. The Germans spent most of their (usually multiple weeks long) stay in the U.K. talking to each other, an interaction characterized by a high degree of social proximity and, usually, a rather low degree of cognitive proximity. On the other hand, their infrequent talks to U.K. company representatives were usually characterized by a high degree of cognitive and a low degree of social proximity. We are able to show that, while there are no signs for any kind of convergence of the Germans' research topics to each other (and no collaborations, either), the U.K. interaction seemed to have a strong impact. The Germans in our sample, which we compare to a Swiss as well as a German control group, experienced a strong increase in interaction with U.K. firms and inventors after their return to Germany, and this increased interaction had long-lasting positive productivity effects. We thus conclude that, when geographic distance is set to zero, social distance can be easily overcome and knowledge flows freely if cognitive distance is low. This knowledge flow is bi-directional, even if it was, as in this case, intended to be unidirectional. On the other hand, it seems very hard to overcome cognitive distances, even if social and geographic distances are very low.

While the studies in this dissertation help fill some of the gaps in the research on knowledge production, they also help highlight some of the areas where further research is needed. Hopefully, they thus contribute to the ever-expanding stock of knowledge on the topic and ever so slightly raise the oft-mentioned shoulders of giants.

Appendix A

Appendix to Chapter 3

A.1 Robustness Checks

See the main article for details.

Table A.1: Regression results explaining citations, outliers excluded

	Dependent variable:			
	Average number of citations (over 3 years) of papers published 0 to 5 years after dissertation			
	(Model 1)	(Model 2)	(Model 3)	(Model 4)
keyword distance	−0.479	−0.732**		
	(0.344)	(0.345)		
abstract distance			−5.853	−6.708
			(5.639)	(5.669)
weighted publication stock 3 years after dissertation		−0.143		−0.121
		(0.488)		(0.502)
female		−7.042***		−6.058**
		(2.387)		(2.359)
institute change		−4.255		−3.604
		(3.863)		(3.903)
theoretical physics		−2.276		−1.977
		(1.643)		(1.664)
dissertation year		−0.130		0.224
		(0.636)		(0.646)
dissertation abroad		4.464*		4.573*
		(2.345)		(2.385)
EN start		0.465		0.205
		(0.513)		(0.524)
Constant	11.989***	-655.647	17.460***	-837.899*
	(2.406)	(477.980)	(2.395)	(479.648)
Observations	127	127	127	127
R^2	0.015	0.154	0.009	0.132
Adjusted R^2	0.007	0.097	0.001	0.074
Residual Std. Error	9.354 (df=125)	8.922 (df=118)	9.386 (df=125)	9.037 (df=118)
F Statistic	1.935 (df=1;125)	2.691*** (df=8;118)	1.077 (df=1;125)	2.250** (df=8;118)

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from OLS regression models, standard errors in parentheses.

Table A.2: Probit regression results explaining awards, outliers excluded

	Dependent variable:			
	Award Received			
	(Model 1)	(Model 2)	(Model 3)	(Model 4)
keyword distance	−0.033	0.005		
	(0.047)	(0.053)		
abstract distance			−0.425	−0.197
			(0.750)	(0.853)
weighted publication stock		0.171**		0.166***
3 years after dissertation		(0.064)		(0.063)
female		0.625**		0.621**
		(0.298)		(0.293)
institute change		0.371		0.364
		(0.590)		(0.591)
theoretical physics		−0.769***		−0.763***
		(0.263)		(0.261)
dissertation year		0.183*		0.184*
		(0.109)		(0.110)
dissertation abroad		−0.293		−0.299
		(0.324)		(0.329)
EN start		−0.137		−0.138
		(0.085)		(0.087)
Constant	−1.131***	−92.347	−0.736**	−91.830
	(0.347)	(68.107)	(0.314)	(67.255)
Observations	158	158	158	158
Log Likelihood	−75.072	-66.254	−75.177	−66.233
Akaike Inf. Crit.	154.144	150.507	154.354	150.467

Note: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Estimates from Probit regression models, robust standard errors in parentheses.

Table A.3: Probit regression results explaining awards, outliers excluded; Marginal effects

	Dependent variable:			
	Award Received			
	(Model 1)	(Model 2)	(Model 3)	(Model 4)
keyword distance	−0.009	−0.002		
	(0.013)	(0.012)		
abstract distance			−0.113	−0.047
			(0.193)	(0.206)
weighted publication stock 3 years after dissertation		0.041***		0.039***
		(0.015)		(0.015)
female		0.177*		0.176*
		(0.095)		(0.092)
institute change		0.073		0.072
		(0.095)		(0.097)
theoretical physics		−0.193***		−0.191***
		(0.068)		(0.067)
dissertation year		0.043*		0.044*
		(0.026)		(0.026)
dissertation abroad		−0.063		−0.064
		(0.062)		(0.062)
EN start		−0.032*		−0.033*
		(0.020)		(0.020)

Note: *** p<0.01, ** p<0.05, * p<0.1. Marginal effects at means for probit regression models, robust standard errors in parentheses.

Appendix B

Appendix to Chapter 5

B.1 Robustness Check with German Control Group

As noted in the main article, an alternative control group of German inventors not subject to the BIOS program is employed to address potential concerns regarding unobservable differences between the treatment group of German inventors subject to the BIOS program and the control group of Swiss inventors. The alternative control group was constructed in an analogous way to the Swiss control group. For each treated inventor, we first searched for an untreated match patenting in the same fine-grained (8-digit) IPC class. In 24 cases, we were unable to identify a suitable match who was sufficiently similar in their time and extent of patenting. This may reflect that the BIOS program picked specialists in narrowly defined fields of expertise. As for the Swiss sample, we resorted to the 4-digit IPC class to find matches in these cases. In this way, German control inventors could be identified for 61 treated German inventors in the main sample. Descriptive statistics for the treated and matched German inventors are listed in Table B.1. Again, the matching process results in a rather balanced sample. On average, matched Germans have a larger number of pre-WW2 patents, but as indicated

Table B.1: Descriptive Statistics (German control group)

	full sample	Germans	Matched Germans	
n	122	61	61	
all patents pre	2395	933	1462	
all patents post	3382	2456	926	
average (median in breakets)				p-value (mean difference)
patents pre	19.63 (8)	15.3 (8)	23.97 (8)	0.21
patents post	27.72 (6)	40.26 (11)	15.18 (4)	0.07
year first patent filed	1931.07 (1932)	1930.75 (1931)	1931.39 (1934)	0.64
years active	30.3 (30)	30.52 (31)	30.07 (28)	0.85
UK affiliation pre	0.02 (0)	0.02 (0)	0.02 (0)	1
UK affiliation post	0.06 (0)	0.11 (0)	0 (0)	0.01
UK applicant pre	0 (0)	0 (0)	0 (0)	
UK applicant post	0.12 (0)	0.25 (0)	0 (0)	0.02
UK co-inventor pre	0.01 (0)	0.02 (0)	0 (0)	0.32
UK co-inventor post	0.06 (0)	0.11 (0)	0 (0)	0.11
US affiliation pre	0.11 (0)	0.02 (0)	0.21 (0)	0
US affiliation post	0.05 (0)	0.02 (0)	0.08 (0)	0.1
US applicant pre	0.52 (0)	0.2 (0)	0.84 (0)	0.03
US applicant post	0.05 (0)	0.02 (0)	0.08 (0)	0.25
US co-inventor pre	0.04 (0)	0 (0)	0.08 (0)	0.17
US co-inventor post	0.03 (0)	0.07 (0)	0 (0)	0.21

Note: Descriptive statistics comparing the group of treated Germans and the second, German, control group. Averages are arithmetic means. U.K./U.S. affiliation pre/post are dummy variables that take the value 1 if there is at least one patent before/after 1947 on which the inventor is listed as having a U.K./U.S. address. U.K./U.S. applicant pre/post and U.K./U.S. co-inventor pre/post count the number of applicants/co-inventors from the U.K./U.S. listed on the inventor's patents before/after 1947.

by the equal median of both groups, the (insignificant) difference is due to a few highly productive inventors in the control group. All other pre-treatment variables are very similar for both groups.[1]

We interpreted the results reported in the main article as evidence of learning during the BIOS detention. This interpretation relies on the credibility of the Swiss control group. One might be concerned that aspects of the post-WW2 rebuilding of the German economy may have favored the

[1] In addition to the control group consisting of 8-digit and 4-digit matches, we also constructed control groups of (only) 8-digit and (only) 4-digit controls. Both these control groups result in poorer matching quality, particularly regarding overall patent output. We nonetheless re-analyzed all models reported below also for these control groups. Unreported results, which are available from the authors, are very similar to those shown below.

Table B.2: U.K. Interaction - Diff-In-Diff Estimates (Matched German Control Group)

number of inventors	Treated Germans pre	Treated Germans post	Matched Germans pre	Matched Germans post	diff-in-diff estimator	quantile cutting zero*
UK address	1	7	1	0	0.11	0
UK co-inventors	1	4	0	0	0.05	0.14
(UK co-inventors total)	1	7	0	0	0.1	0.09
UK applicants	0	9	0	0	0.15	0
(UK applicants total)	0	15	0	0	0.25	0
any kind of UK interaction	2	10	1	0	0.13	0

Note: * bootstrapped with 1000 iterations. Calculation estimating whether the difference in differences of the means of UK-interaction variables between treatment group and German control group deviates from zero. "U.K. address" measures whether or not an inventor moved his residency to the U.K. "U.K. co-inventors" and "U.K. applicants" measures whether or not an inventor has co-inventors/applicants from the U.K.. Total number of U.K. co-inventors measures the number of co-inventors from the U.K. listed for the inventors in the two groups. Total number of U.K. applicants does the same for applicants located in the U.K.. "Any kind of U.K. interaction" measures whether or not an inventor had U.K. affiliation and/or applicants and/or co-inventors.

patenting activities of German inventors. The real cause for the observed effects in our sample of treated German inventors might then be (partially) unrelated to the BIOS treatment. To assess the relevance of such concerns, we replicate the analysis using the alternative control group of matched German inventors. To the best of our knowledge, none of them was subjected to the BIOS program. However, given the multitude of similar post-WW2 programs, we cannot entirely rule out that members of the German control group were subject to a treatment similar to BIOS, which is why we consider it inferior to the Swiss control group.

The univariate difference-in-differences estimation concerning UK-interaction of treated Germans as compared to untreated Germans (Table B.2) leads to very similar results as in the main article, where the treated Germans were compared to their Swiss counterparts. We find no interaction of any kind between the German controls and U.K. inventors after 1947, which is in stark contrast to the increase in all kinds of interaction in the treatment group. As for the Swiss control group, the diff-in-diff estimators are significant for all types of interaction except for UK co-inventors. This robustness check therefore provides additional support for Hypothesis 1.

Pre-1947 patenting activities develop similarly among the treated Germans and the German control inventors (cf. Figures B.1a and B.1b). This allows us to replicate our test of Hypothesis 2 employing a difference-in-difference analysis of patent counts. Results of this robustness check are almost identical to those obtained with the Swiss control group. Again, the interaction term is positive, sizable and highly significant in Models 1-3, providing further support for Hypothesis 2.

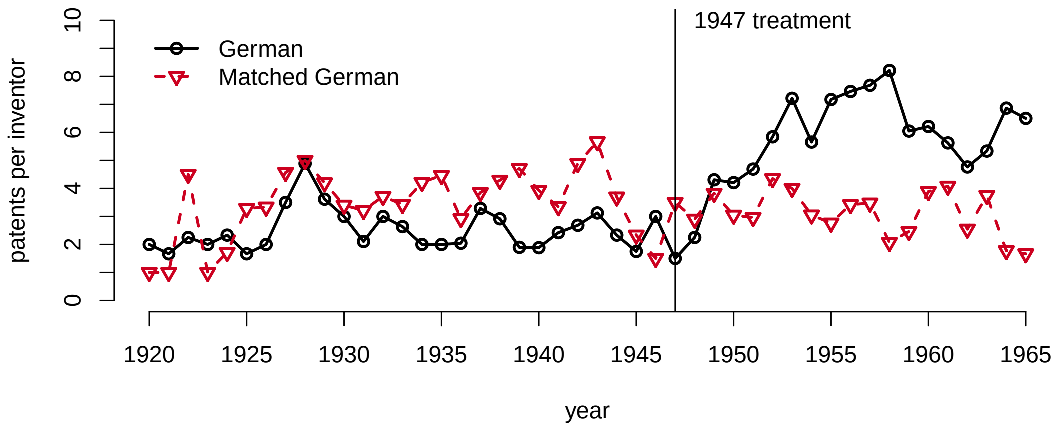
Hypothesis 3.a posited the importance of cognitive proximity for interactive learning. It was tested by relating post-WW2 increases in patent output to indicators of U.K. interaction, which we replicate using the German control group (Table B.4). Model 1 again indicates a positive treatment effect on researcher productivity. Including shares of post-1947 patents with U.K. and U.S. applicants in Model 2, we estimate a positive but insignificant coefficient for the U.K. share and a negative and insignificant one for the U.S. Models 3 and 4 suggest a positive and marginally significant effect of having co-inventors from the U.K., whereas U.S. co-inventors appear to be unrelated to researcher productivity. All these results are very similar to those obtained using the Swiss control group. They are consistent with our interpretation that the increase in patenting after the BIOS treatment was due to the interaction with British experts, where learning was enabled by cognitive proximity.

Our final piece of empirical evidence relates to Hypothesis 3.b. In the main article we had shown that the post-1947 patents of German inventors subjected to the BIOS treatment were far more likely to cite U.K. patents when they fell into IPC classes that the respective inventor had been active in before the treatment. Since the BIOS interrogations referred to their existing fields of expertise, this was taken as evidence of a BIOS effect on the German experts. This interpretation finds additional support by our replication of the citation analysis for the members of the German control group (see Table B.5). Here, citations to U.K. patents do not differ systematically between patents in new-to-the-researcher IPCs versus old-to-the-researcher IPCs.

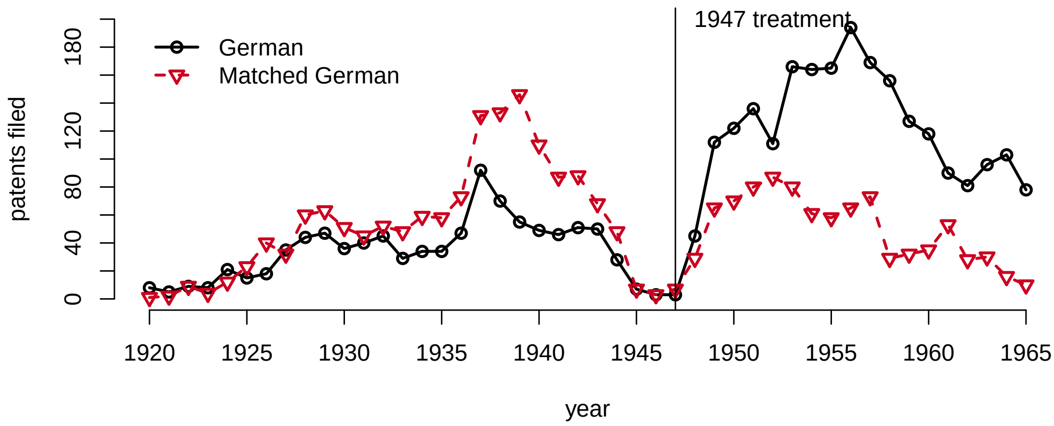
Table B.3: Regression Results on the Productivity of Inventors (Matched German Control Group)

	Dependent variable:		
	number of patents applied (in period t)		
	(1)	(2)	(3)
post1947∗treat	1.189***	1.124***	1.118***
	(0.260)	(0.316)	(0.208)
post1947	−0.525***		
	(0.163)		
treat	−0.377*	−0.233	−.0279
	(0.205)	(0.236)	(0.401)
year first patent filed	−0.049***	−0.082***	−0.059***
	(0.015)	(0.016)	(0.014)
(Intercept)	95.807***	155.458***	119.458***
	(28.099)	(32.139)	(28.338)
IPC dummmies	Yes	Yes	Yes
period effects	No	Yes	Yes
individual time effects	No	No	Yes
Observations	244	1,220	1,220
Log Likelihood	−891.759	−2,352.439	−2,432.138
Akaike Inf. Crit.	1,811.519	4,748.878	4,892.275

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from negative binomial regression models. Robust clustered (on inventor level) standard errors in parentheses. Estimates from negative binomial regression models. Robust clustered (on inventor level) standard errors in parentheses. Treatment dummy denotes detention in the BIOS program. Control group includes comparable non-treated German inventors. IPC dummies at first letter level (A-H). Pre-/post-treatment observations are pooled in Model 1. Models 2 and 3 distinguish eight 5-year periods as well as the years before 1922/after 1961. Model 3 includes a full set of inventor-specific time-trends.



(a) Average Number of Patents Filed per (Patenting) Inventor (Matched German Control Group)



(b) Number of Patents Filed

Figure B.1: Patents Filed per Year and Group (Matched German Control Group)

Table B.4: Regression Results Explaining Post 1947 Patent Outputs (Matched German Control Group)

	Dependent variable:			
	percentage change in patenting activity			
	(1)	(2)	(3)	(4)
German (treat)	3.461**	2.910	2.794*	2.968*
	(1.745)	(1.794)	(1.669)	(1.694)
year first patent filed	0.277***	0.240**	0.226**	0.218**
	(0.105)	(0.098)	(0.100)	(0.101)
nbr patents pre 1947	−0.050*	−0.051*	−0.050*	−0.046*
	(0.029)	(0.030)	(0.029)	(0.027)
UK applicants post 1947 (share)		9.519		
		(10.323)		
US applicants post 1947 (share)		−17.468		
		(12.654)		
UK co-inv. post 1947 (share)			25.242*	25.271*
			(13.293)	(13.732)
US co-inv. post 1947 (share)			5.053	4.820
			(5.858)	(5.813)
patents in new IPC (share)				−1.359
				(1.791)
(Intercept)	−541.098***	−468.550**	−441.928**	−424.784**
	(204.604)	(189.739)	(194.340)	(196.398)
IPC dummmies	Yes	Yes	Yes	Yes
Observations	122	122	122	122
R^2	0.277	0.294	0.304	0.306
Adjusted R^2	0.205	0.209	0.220	0.215
Residual Std. Error	9.888 (df = 110)	9.858 (df = 108)	9.791 (df = 108)	9.825 (df = 107)
F Statistic	3.831*** (df = 11; 110)	3.465*** (df = 13; 108)	3.629*** (df = 13; 108)	3.364*** (df = 14; 107)

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from OLS regression models, (robust) standard errors in parentheses. Patenting activities with U.K./U.S. applicants/co-inventors are measured through their shares among overall patent applications per inventor. "Patents in new IPC" measures the share of applications per inventor that fall into subjectively new IPC classes.

Table B.5: Citations of "Old" and "New" IPC Patents (Matched German Control Group)

	patents in:		(p-value)
mean citations to	new IPC	old IPC	mean difference
U.K. patents	0.14	0.10	0.25
U.S. patents	0.63	0.80	0.24
German patents	0.74	0.50	0.03

Note: Average number of backward citations found in post-1947 patent applications filed by inventors in the German control group. New (old) IPC refers to patents that (do not) have at least one subjectively new IPC class.

B.2 Further Robustness Checks

See the main article for details.

Table B.6: Regression Results on the Productivity of Inventors (Outliers Excluded)

	Dependent variable:		
	number of patents applied (in period t)		
	(1)	(2)	(3)
post1947*treat	0.705***	0.812***	0.684***
	(0.221)	(0.241)	(0.164)
post1947	−0.425***		
	(0.153)		
treat	0.212	0.112	0.510
	(0.174)	(0.175)	(0.316)
year first patent filed	−0.028***	−0.038***	−0.03***
	(0.008)	(0.008)	(0.007)
(Intercept)	54.264***	72.127***	56.41***
	(15.171)	(15.664)	(15.141)
IPC dummmies	Yes	Yes	Yes
period effects	No	Yes	Yes
individual time effects	No	No	Yes
Observations	224	1,120	1,120
Log Likelihood	−743.455	−2,053.601	−2,077.739
Akaike Inf. Crit.	1,514.909	4,149.202	4,183.478

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from negative binomial regression models. Robust clustered standard errors in parentheses. Estimates from negative binomial regression models. Robust clustered (on inventor level) standard errors in parentheses. Treatment dummy denotes detention in the BIOS program. Control group includes comparable Swiss inventors. IPC dummies at first letter level (A-H). Pre-/post-treatment observations are pooled in Model 1. Models 2 and 3 distinguish eight 5-year periods as well as the years before 1922 / after 1961. Model 3 includes a full set of inventor-specific time-trends. All German inventors, and their Swiss counterfactuals, with more than 180 patents (equal to the mean plus two times the standard deviation) were excluded from the sample.

Table B.7: Regression Results on the Productivity of Inventors (U.K. Interaction)

	Dependent variable:		
	number of patents applied (in period t)		
	(1)	(2)	(3)
post1947*treat	1.269***	1.144***	0.946***
	(0.381)	(0.265)	(0.194)
post1947	−0.357**		
	(0.167)		
treat	0.173	0.168	0.727**
	(0.228)	(0.175)	(0.317)
year first patent filed	−0.017	−0.040***	−0.03***
	(0.013)	(0.008)	(0.007)
UK interaction	−0.069	0.991***	0.869***
	(0.058)	(0.342)	(0.252)
Intercept	34.457	74.226***	56.007***
	(24.858)	(15.979)	(14.912)
IPC dummmies	Yes	Yes	Yes
period effects	No	Yes	Yes
individual time effects	No	No	Yes
Observations	232	1,160	1,160
Log Likelihood	−862.493	−2,234.069	−2,256.518
Akaike Inf. Crit.	1,752.986	4,512.137	4,543.036

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from negative binomial regression models. Robust clustered (on inventor level) standard errors in parentheses. Treatment dummy denotes detention in the BIOS program. Control group includes comparable Swiss inventors. IPC dummies at first letter level (A-H). Pre-/post-treatment observations are pooled in Model 1. Models 2 and 3 distinguish eight 5-year periods as well as the years before 1922 / after 1961. Model 3 includes a full set of inventor-specific time-trends. U.K. interaction dummy denotes all inventors with at least one U.K. address, co-inventor or applicant.

Table B.8: Regression Results Explaining Post 1947 Patent Outputs (Outliers excluded)

	Dependent variable:			
	percentage change in patenting activity			
	(1)	(2)	(3)	(4)
German (treat)	2.088***	1.345*	1.539**	1.393**
	(0.788)	(0.724)	(0.657)	(0.630)
year first patent filed	0.084***	0.072**	0.066**	0.066**
	(0.033)	(0.032)	(0.031)	(0.031)
nbr patents pre 1947	−0.069**	−0.050**	−0.047**	−0.059**
	(0.030)	(0.020)	(0.019)	(0.026)
UK applicants post 1947 (share)		13.493		
		(9.866)		
US applicants post 1947 (share)		−4.010**		
		(1.882)		
UK co-inv. post 1947 (share)			26.117*	26.001*
			(14.052)	(13.737)
US co-inv. post 1947 (share)			−2.262**	−2.101**
			(1.072)	(1.054)
patents in new IPC (share)				1.155
				(0.776)
(Intercept)	−163.355***	−138.781**	−128.638**	−127.904**
	(62.860)	(62.232)	(59.655)	(59.843)
IPC dummmies	Yes	Yes	Yes	Yes
Observations	112	112	112	112
R^2	0.240	0.373	0.458	0.466
Adjusted R^2	0.156	0.290	0.386	0.389
Residual Std. Error	3.848 (df = 100)	3.530 (df = 98)	3.282 (df = 98)	3.276 (df = 97)
F Statistic	2.871*** (df = 11; 100)	4.484*** (df = 13; 98)	6.373*** (df = 13; 98)	6.039*** (df = 14; 97)

Note: *** p<0.01, ** p<0.05, * p<0.1. Estimates from OLS regression models, (robust) standard errors in parentheses. All German inventors, and their Swiss counterfactual, with more than 180 patents (equal to the mean plus two times the standard deviation) are excluded from the sample.

Bibliography

Adams, J. (2005). Early citation counts correlate with accumulated impact. *Scientometrics*, 63(3):567–581.

Adams, J., Jackson, L., and Marshall, S. (2007). Bibliometric analysis of interdisciplinary research. Technical report.

Agarwal, R., Echambadi, R., Franco, A. M., and Sarkar, M. B. (2004). Knowledge transfer through inheritance: Spin-out generation, development, and survival. *Academy of Management Journal*, 47:501–522.

Agrawal, A., Cockburn, I., and McHale, J. (2006). Gone but not forgotten: Knowledge flows, labor mobility, and enduring social relationships. *Journal of Economic Geography*, 6(5):571–591.

Albach, H. (1993). *Zerrissene Netze: eine Netzwerkanalyse des ostdeutschen Transformationsprozesses*. edition sigma, Berlin.

Alcácer, J. and Chung, W. (2007). Location strategies and knowledge spillovers. *Management Science*, 53(5):760–776.

Alesina, A. and Fuchs-Schündeln, N. (2007). Good-bye Lenin (or not?): The effect of communism on people's preferences. *American Economic Review*, 97(4):1507–1528.

Arora, S., Ge, R., Halpern, Y., Mimno, D., Moitra, A., Sontag, D., Wu, Y., and Zhu, M. (2013). A practical algorithm for topic modeling with provable guarantees. In *30th International Conference on Machine Learning, ICML 2013*.

Arrow, K. J. (1962). The Economic Implications of Learning by Doing. *The Review of Economic Studies*, 29(3):155–173.

Åstebro, T., Bazzazian, N., and Braguinsky, S. (2012). Startups by recent university graduates and their faculty: Implications for university entrepreneurship policy. *Research Policy*, 41(4):663–677.

Åstebro, T., Herz, H., Nanda, R., and Weber, R. A. (2014). Seeking the roots of entrepreneurship: Insights from behavioral economics. *Journal of Economic Perspectives*, 28(3):49–70.

Audretsch, D. B. and Feldman, M. P. (1996). R&D spillovers and the geography of innovation and production. *The American Economic Review*, 86(3):630–640.

Azoulay, P., Fons-Rosen, C., and Zivin, J. S. G. (2019). Does Science Advance One Funeral at a Time? *American Economic Review*, 109(8):2889–2920.

Azoulay, P., Graff Zivin, J. S., and Manso, G. (2011). Incentives and creativity: Evidence from the academic life sciences. *RAND Journal of Economics*, 42(3):527–554.

Bäker, A. (2015). Non-tenured post-doctoral researchers' job mobility and research output: An analysis of the role of research discipline, department size, and coauthors. *Research Policy*, 44(3):634–650.

Bercovitz, J. and Feldman, M. (2008). Academic entrepreneurs: Organizational change at the individual level. *Organization Science*, 19(1):69–89.

Biasi, B. and Moser, P. (2017). Effects of copyrights on science - evidence from the US book republication program. *Mimeo*.

Blei, D. M. (2012). Probabilistic topic models. In *Communications of the ACM*.

Blei, D. M. and Lafferty, J. D. (2007). A correlated topic model of Science. *The Annals of Applied Statistics*, 1(1):17–35.

Borjas, G. J. and Doran, K. B. (2012). The collapse of the soviet union and the productivity of american mathematicians. *Quarterly Journal of Economics*, 127(3):1143–1203.

Borjas, G. J. and Doran, K. B. (2015a). Cognitive mobility: Labor market responses to supply shocks in the space of ideas. *Journal of Labor Economics*, 33(1):109–145.

Borjas, G. J. and Doran, K. B. (2015b). Which peers matter? The relative impacts of collaborators, colleagues, and competitors. *The Review of Economics and Statistics*, 97(5):1104–1117.

Boschma, R. (2005). Proximity and innovation: A critical assessment. *Regional Studies*, 39(1):61–74.

Breschi, S. and Lissoni, F. (2001). Knowledge spillovers and local innovation systems: A critical survey. *Industrial and Corporate Change*, 10(4):975–1005.

Breschi, S. and Lissoni, F. (2009). Mobility of skilled workers and co-invention networks: An anatomy of localized knowledge flows. *Journal of Economic Geography*, 9(4):439–468.

Broekel, T. and Boschma, R. (2012). Knowledge networks in the Dutch aviation industry: the proximity paradox. *Journal of Economic Geography*, 12(2):409–433.

Bruce, A., Lyall, C., Tait, J., and Williams, R. (2004). Interdisciplinary integration in Europe: The case of the Fifth Framework programme. *Futures*, 36(4):457–470.

Bruns, S. B. and Stern, D. I. (2016). Research assessment using early citation information. *Scientometrics*, 108(2):917–935.

Buenstorf, G. and Geissler, M. (2014). Like Doktorvater, like son? Tracing role model learning in the evolution of German laser research. *Journal of Economics and Statistics*, 234(2-3):158–184.

Buenstorf, G. and Heinisch, D. P. (2020). When do firms get ideas from hiring PhDs? *Research Policy*, 49(3).

Buenstorf, G. and Klepper, S. (2009). Heritage and agglomeration: The akron tyre cluster revisited. *Economic Journal*, 119(537):705–733.

Buenstorf, G., Nielsen, K., and Timmermans, B. (2017). Steve Jobs or No Jobs? Entrepreneurial activity and performance among Danish college dropouts and graduates. *Small Business Economics*, 48(1):179–197.

Burchardi, K. B. and Hassan, T. A. (2013). The economic impact of social ties: Evidence from german reunification. *Quarterly Journal of Economics*, 128(3):1219–1271.

Cairncross, F. (2001). *The death of distance: How the communications revolution is changing our lives*. Harvard Business School Press, Boston, MA, 2nd edition.

Christensen, C. M. (1993). The Rigid Disk Drive Industry: A History of Commercial and Technological Turbulence. *Business History Review*, 67:531–588.

Coase, R. H. (1937). The Nature of the Firm. *Economica*, 4(16):386–405.

Cockburn, I. M. and Henderson, R. M. (1998). Absorptive capacity, coauthoring behavior, and the organization of research in drug discovery. *The Journal of Industrial Economics*, 46(2):157–182.

Cohen, W. M. and Levinthal, D. A. (1989). Innovation and learning: The two faces of R & D. *The Economic Journal*, 99(397):569–596.

Cohen, W. M. and Levinthal, D. A. (1990). Absorptive Capacity: A New Perspective on Learning and Innovation. *Administrative Science Quarterly*, 35(1):128–152.

Crane, D. (1965). Scientists at major and minor universities: a study of productivity and recognition. *American sociological review*, 30(5):699–714.

Crescenzi, R., Nathan, M., and Rodríguez-Pose, A. (2016). Do inventors talk to strangers? On proximity and collaborative knowledge creation. *Research Policy*, 45(1):177–194.

Cummings, J. N. and Kiesler, S. (2005). Collaborative research across disciplinary and organizational boundaries. *Social Studies of Science*, 35(5):703–722.

Czarnitzki, D., Doherr, T., Hussinger, K., Schliessler, P., and Toole, A. A. (2016). Knowledge Creates Markets: The influence of entrepreneurial support and patent rights on academic entrepreneurship. *European Economic Review*, 86:131–146.

Dasgupta, P. and David, P. A. (1994). Toward a new economics of science. *Research Policy*, 23(5):487–521.

Dorner, M., Harhoff, D., Hinz, T., Hoisl, K., and Bender, S. (2016). Social Ties for Labor Market Access – Lessons from the Migration of East German Inventors. *CEPR Discussion Paper No. DP11601.*

Duranton, G. and Overman, H. G. (2005). Testing for localization using micro- geographic data. *Review of Economic Studies*, 72(4):1077–1106.

Ejermo, O., Fassio, C., and Källström, J. (2019). Does Mobility across Universities Raise Scientific Productivity? *Oxford Bulletin of Economics and Statistics.*

Ellison, G. and Glaeser, E. L. (1997). R&D spillovers and the geography of innovation and production. *Journal of Political Economy*, 105(5):889–927.

European Patent Office (2019). European companies and inventors file more patent applications in 2018.

Feldman, M. P. and Kogler, D. F. (2010). Stylized facts in the geography of innovation. In Hall, B. H. and Rosenberg, N., editors, *Handbook of the Economics of Innovation*, volume 1, pages 381–410. Elsevier, Amsterdam, The Netherlands.

Fernández-Zubieta, A., Geuna, A., and Lawson, C. (2016). Productivity pay-offs from academic mobility: Should i stay or should i go? *Industrial and Corporate Change*, 25:91–114.

Fleming, L. (2001). Recombinant uncertainty in technological search. *Management Science*, 47(1):117–132.

Foray, D. (2004). *Economics of Knowledge.* MIT Press, Cambridge, MA.

Fox, M. F. and Stephan, P. E. (2001). Careers of young scientists: Preferences, prospects and realities by gender and field. *Social Studies of Science*, 31(1):109–122.

Franzoni, C. and Lissoni, F. (2012). Academic entrepreneurs: critical issues and lessons for Europe. In Varga, A., editor, *Universities, Knowledge Transfer And Regional Development.* Edward Elgar.

Franzoni, C., Scellato, G., and Stephan, P. (2014). The mover's advantage: The superior performance of migrant scientists. *Economics Letters*, 122(1):89–93.

Frey, B. S. (2007). Awards as compensation. *European Management Review*, 4(1):6–14.

Fuhrmann, C. N., Halme, D. G., O'Sullivan, P. S., and Lindstaedt, B. (2011). Improving graduate education to support a branching career pipeline: Recommendations based on a survey of doctoral students in the basic biomedical sciences. *CBE Life Sciences Education*, 10(3):239–249.

Furman, J. L. and Heinisch, D. P. (2019). Tied to apron strings of knowledge. *Mimeo*.

Furman, J. L. and Teodoridis, F. (2018). Automation, Research Technology, and Researchers' Trajectories: Evidence from Computer Science and Electrical Engineering. *SSRN Electronic Journal*.

Garvey, W. D. and Tomita, K. (1972). Continuity of Productivity By Scientists in the Years 1968–71. *Social Studies of Science*, 2(4):379–383.

Gentzkow, M., Kelly, B., and Taddy, M. (2019). Text as data. *Journal of Economic Literature*, 57(3):535–574.

Gieryn, T. F. (1978). Problem Retention and Problem Change in Science. *Sociological Inquiry*, 48(3-4):96–115.

Gimbel, J. (1990a). Deutsche Wissenschaftler in britischem Gewahrsam. Ein Erfahrungsbericht aus dem Jahre 1946 über das Lager Wimbledon. *Vierteljahrshefte für Zeitgeschichte*, 38(3):459–483.

Gimbel, J. (1990b). *Science, technology, and reparations. Exploitation and plunder in postwar Germany.* Stanford University Press, Stanford, CA.

Grabher, G. and Stark, D. (1997). Organizing diversity: Evolutionary theory, network analysis and postsocialism. *Regional Studies*, 31(5):533–544.

Granovetter, M. (1985). Economic action and social structure: The problem of embeddedness. *American Journal of Sociology*, 91(3):481–510.

Günther, O. and Schmerbach, S. (2010). Deutsche Universitäten im Umbruch – 20 Jahre nach der Wende. In Keuper, F. and Puchta, D., editors, *Deutschland 20 Jahre nach dem Mauerfall*, pages 399–417. Gabler, Wiesbaden.

Hall, B. H., Mairesse, J., and Turner, L. (2007). Identifying age, cohort, and period effects in scientific research productivity: Discussion and illustration using simulated and actual data on french physicists. *Economics of Innovation and New Technology*, 16(2):159–177.

Hall, D., Jurafsky, D., and Manning, C. D. (2008). Studying the history of ideas using topic models. In *EMNLP 2008 - 2008 Conference on Empirical Methods in Natural Language Processing, Proceedings of the Conference: A Meeting of SIGDAT, a Special Interest Group of the ACL.*

Haugh, H. (2006). Nonprofit social entrepreneurship. In Parker, S. C., editor, *The Life Cycle of Entrepreneurial Ventures*, pages 401–436. Springer, New York.

Helfat, C. E. and Lieberman, M. B. (2002). The birth of capabilities: market entry and the importance of pre-history. *Industrial and Corporate Change*, 11(4):725–760.

Helmers, C. and Overman, H. G. (2017). My precious! The location and diffusion of scientific research: evidence from the synchrotron diamond light source. *The Economic Journal*, 127(604):2006–2040.

Higgins, M. C. (2005). *Career imprints: Creating leaders across an industry.* John Wiley & Sons.

Horlings, E. and Gurney, T. (2013). Search strategies along the academic lifecycle. *Scientometrics*, 94(3):1137–1160.

Hottenrott, H. and Lawson, C. (2017). Flying the nest: how the home department shapes researchers' career paths. *Studies in Higher Education*, 42(6):1091–1109.

Huber, F. (2012). On the role and interrelationship of spatial, social and cognitive proximity: Personal knowledge relationships of R&D workers in the Cambridge information technology cluster. *Regional Studies*, 46(9):1169–1182.

Huutoniemi, K., Klein, J. T., Bruun, H., and Hukkinen, J. (2010). Analyzing interdisciplinarity: Typology and indicators. *Research Policy*, 39(1):79–88.

Jacobsen, A. (2014). *Operation Paperclip. The secret intelligence program that brought Nazi scientists to America.* Little, Brown and Company, New York, first edit edition.

Jaffe, A. B. and Trajtenberg, M. (1996). Flows of knowledge from universities and federal laboratories: Modeling the flow of patent citations over time and across institutional and geographic boundaries. *Proceedings of the National Academy of Sciences*, 93(23):12671–12677.

Jaffe, A. B., Trajtenberg, M., and Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics*, 108(3):577–598.

Jöns, H. (2009). 'Brain circulation' and transnational knowledge networks: studying long-term effects of academic mobility to Germany. *Global Networks*, 9(3):315–338.

Jungbauer-Gans, M. and Gross, C. (2013). Determinants of success in university careers: Findings from the German academic labor market. *Zeitschrift fur Soziologie*, 42(1):74–92.

Kahn, L. B. (2010). The long-term labor market consequences of graduating from college in a bad economy. *Labour Economics*, 17(2):303–316.

Kaplan, S. and Vakili, K. (2015). The double-edged sword of recombination in breakthrough innovation. *Strategic Management Journal*, 36(10):1435–1457.

Kirzner, I. M. (1973). *Competiton & Entrepreneurship*. The University of Chicago Press, Chicago and London.

Klepper, S. and Sleeper, S. (2005). Entry by spinoffs. *Management Science*, 51(8):1291–1306.

Knight, F. H. (1922). *Risk, Uncertainty and Profit*. Houghton Mifflin.

Krabel, S. (2012). Scientists' valuation of open science and commercialization: The influence of peers and organizational context. In Buenstorf, G., editor, *Evolution, Organization and Economic Behavior*, pages 75–102. Edward Elgar.

Krücken, G. and Meier, F. (2006). Turning the University into an Organizational Actor. In Drori, G. S., Meyer, J. W., and Hwang, H., editors, *Globalization and Organization: World Society and Organizational Change*, pages 241–257. Oxford University Press.

Kuhn, T. S. (1962). *The structure of scientific revolutions*. University of Chicago press, Chicago and London.

Kwon, S., Liu, X., Porter, A. L., and Youtie, J. (2019). Research addressing emerging technological ideas has greater scientific impact. *Research Policy*, 48(9).

Larivière, V. and Gingras, Y. (2010). On the relationship between interdisciplinary and scientific impact. *Journal of the American Society for Information Science and Technology*, 61(1):126–131.

Lasby, C. G. (1971). *Project Paperclip: German scientists and the Cold War.* Atheneum, New York, NY.

Lawson, C. and Soós, S. (2014). *A Thematic Mobility Measure for Econometric Analysis.* Number 02/2014. LEI &BRICK Working Paper.

Lehmann-Brauns, S. (2005). Independence for Young German Scientists.

Levin, S. G. and Stephan, P. E. (1991). Research Productivity Over the Life Cycle: Evidence for Academic Scientists. *The American Economic Review*, 81(1):114–132.

Long, J. S. and McGinnis, R. (1985). The effects of the mentor on the academic career. *Scientometrics*, 7(3-6):255–280.

Macrakis, K. (1993). *Surviving the Swastika: Scientific research in Nazi Germany.* Oxford University Press, Oxford, UK.

Malmgren, R. D., Ottino, J. M., and Nunes Amaral, L. A. (2010). The role of mentorship in protégé performance. *Nature*, 465(7298):622–626.

Marshall, A. (1920). *Principles of Economics.* Macmillan, London, UK, 8th edition.

Merton, R. K. (1957). Priorities in Scientific Discovery: A Chapter in the Sociology of Science. *American Sociological Review*, 22(6):635–659.

Merton, R. K. (1973). *The sociology of science: Theoretical and empirical investigations.* University of Chicago press, Chicago and London.

Metcalfe, J. S. (1994). Evolutionary Economics and Technology Policy. *The Economic Journal*, 104(425):931–944.

Moser, P., Voena, A., and Waldinger, F. (2014). German Jewish émigrés and US invention. *American Economic Review*, 104(10):3222–3255.

Murmann, J. P. (2003). *Knowledge and competitive advantage: The coevolution of firms, technology, and national institutions*. Cambridge University Press, Cambridge, UK.

Myers, K. (2018). The Elasticity of Science. *SSRN Electronic Journal*.

Narin, F. and Noma, E. (1985). Is technology becoming science? *Scientometrics*, 7:369–381.

Nelson, R. R. (2008). What enables rapid economic progress: What are the needed institutions? *Research Policy*, 37(1):1–11.

Nelson, R. R. and Winter, S. G. (1982). *An Evolutionary Theory of Economic Change*. Harvard University Press, Cambridge, MA.

Nooteboom, B., Haverbeke, W. V., Duysters, G., Gilsing, V., and Oord, A. V. D. (2007). Optimal cognitive distance and absorptive capacity. *Research Policy*, 36(7):1016–1034.

Okamura, K. (2019). Interdisciplinarity revisited: evidence for research impact and dynamism. *Palgrave Communications*, 5.

Oreopoulos, P., von Wachter, T., and Heisz, A. (2012). The short- and long-term career effects of graduating in a recession. *American Economic Journal: Applied Economics*, 4(1):1–29.

Oyer, P. (2006). Initial labor market conditions and long-term outcomes for economists. *Journal of Economic Perspectives*, 20(3):143–160.

Oyer, P. (2008). The making of an investment banker: Stock market shocks, career choice, and lifetime income. *Journal of Finance*, 63(6):2601–2628.

Page, S. E. (2008). *The Difference: How the power of diversity creates better groups, firms, schools, and societies*. Princeton University Press, Princeton, NJ.

Parker, S. C. (2009). *The economics of entrepreneurship*. Cambridge University Press.

Polanyi, M. (1958). *Personal Knowledge: Towards a Post-Critical Phylosophy.* University of Chicago press, Chicago.

Polanyi, M. (1962). *Personal knowledge: Towards a post-critical philosophy.* Harper, New York.

Polanyi, M. (1966). *The tacit dimension.* Anchor, Garden City, NY.

Porter, A. L. and Rafols, I. (2009). Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. *Scientometrics*, 81(719).

Powell, W. W. and Snellman, K. (2004). The Knowledge Economy. *Annual Review of Sociology*, 30:199–220.

Rafols, I. and Meyer, M. (2007). Diversity measures and network centralities as indicators of interdisciplinarity: Case studies in BionanoScience. In *Proceedings of ISSI 2007 - 11th International Conference of the International Society for Scientometrics and Informetrics.*

Rappa, M. and Debackere, K. (1993). Youth and scientific innovation: The role of young scientists in the development of a new field. *Minerva*, 31(1):1–20.

Rehs, A. (2019). Disciplines at the crossroads: Scientific re-orientation of economics and chemistry after German reunification. In *17th International Conference on Scientometrics and Informetrics, ISSI 2019 - Proceedings.*

Renneberg, M. and Walker, M. (1994). Scientists, engineers and national socialism. In Rennerberg, M. and Walker, M., editors, *Science, Technology and National Socialism.* Cambridge University Press, Cambridge, UK.

Rinia, E. J., Van Leeuwen, T. N., Van Vuren, H. G., and Van Raan, A. F. (2001). Influence of interdisciplinarity on peer-review and bibliometric evaluations in physics research. *Research Policy*, 30(3):357–361.

Roach, M. and Sauermann, H. (2010). A taste for science? PhD scientists' academic orientation and self-selection into research careers in industry. *Research Policy*, 39(3):422–434.

Roach, M. and Sauermann, H. (2017). The declining interest in an academic career. *PLoS ONE*, 12(9).

Roberts, M. E., Stewart, B. M., Tingley, D., Lucas, C., Leder-Luis, J., Gadarian, S. K., Albertson, B., and Rand, D. G. (2014). Structural topic models for open-ended survey responses. *American Journal of Political Science*, 58(4):1064–1082.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy*, 98(5, Part 2):71–102.

Rothaermel, F. T., Agung, S. D., and Jiang, L. (2007). University entrepreneurship: A taxonomy of the literature. *Industrial and Corporate Change*, 16(4):691–791.

Salter, A., Salandra, R., and Walker, J. (2017). Exploring preferences for impact versus publications among UK business and management academics. *Research Policy*, 46(10):1769–1782.

Sauermann, H. and Cohen, W. M. (2010). What makes them tick? Employee motives and firm innovation. *Management Science*, 56(12):2134–2153.

Sauermann, H. and Roach, M. (2012). Science PhD career preferences: Levels, changes, and advisor encouragement. *PLoS ONE*, 7(5).

Sauermann, H. and Roach, M. (2014). Not all scientists pay to be scientists: PhDs' preferences for publishing in industrial employment. *Research Policy*, 43(1):32–47.

Schrader, S. (1991). Informal technology transfer between firms: Cooperation through information trading. *Research Policy*, 20(2):153–170.

Schulze, G. G., Warning, S., and Wiermann, C. (2008). What and how long does it take to get tenure? The case of economics and business administration in Austria, Germany and Switzerland. *German Economic Review*, 9(4):473–505.

Schumpeter, J. A. (1911). *Die Theorie der wirtschaftlichen Entwicklung*. Duncker & Humblot, München.

Shane, S. (2000). Prior Knowledge and the Discovery of Entrepreneurial Opportunities. *Organization Science*, 11(4):448–469.

Shane, S. (2003). *A general theory of entrepreneurship: The individual-opportunity nexus*. Edward Elgar, Cheltenham, UK.

Shinn, T. and Benguigui, G. (1997). Physicists and intellectual mobility. *Social Science Information*, 36(2):293–309.

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics*, 70(1):65–94.

Statistisches Bundesamt (2015). Zahl der Habilitationen stieg im Jahr 2014 um 4%. Press release 222.

Steele, T. W. and Stier, J. C. (2000). The impact of interdisciplinary research in the environmental sciences: A forestry case study. *Journal of the American Society for Information Science and Technology*, 51(5):476–484.

Stephan, P. E. (1996). The Economics of Science. *Journal of Economic Literature*, 34(3):1199–1235.

Stephan, P. E. (2012). *How Economics Shapes Science*. Harvard University Press, Cambridge, MA.

Stephan, P. E., Sumell, A. J., Adams, J. D., and Black, G. C. (2005). Firm Placements of New PhDs: Implications for Knowledge Transfer. In Fornahl, D., Zellner, C., and Audretsch, D. B., editors, *The Role of Labour Mobility and Informal Networks for Knowledge Transfer*, pages 125–146. Springer, New York.

Stern, S. (2004). Do scientists pay to be scientists? *Management Science*, 50(6):835–853.

Stirling, A. (2007). A general framework for analysing diversity in science, technology and society. *Journal of the Royal Society Interface*, 4(15):707–719.

Tartari, V., Perkmann, M., and Salter, A. (2014). In good company: The influence of peers on industry engagement by academic scientists. *Research Policy*, 43(7):1189–1203.

Technical University of Munich (TUM) (2018). Mission Statement. *Available online at: https://www.tum.de/en/about-tum/our-university/mission-statement/neste/7/.*

U.S. Bureau of Transportation Statistics (2017). National transportation statistics table 1-40: U.S. passenger-miles (millions).

Uzzi, B., Mukherjee, S., Stringer, M., and Jones, B. (2013). Atypical combinations and scientific impact. *Science*, 342(6157):468–472.

Van Rijnsoever, F. J. and Hessels, L. K. (2011). Factors associated with disciplinary and interdisciplinary research collaboration. *Research Policy*, 40(3):463–472.

Venkataraman, S. (1997). The distinctive domain of entrepreneurship research. *Advances in Entrepreneurship, Firm Emergence and Growth*, 3(1):119–138.

VHB (2019). Aufgaben, Organisation und Geschichte des Verbandes.

von Colbe, W. B. (1996). Accounting and the business economics tradition in Germany. *European Accounting Review*, 5(3):413–434.

Von Hippel, E. (1987). Cooperation between rivals: Informal know-how trading. *Research Policy*, 16(6):291–302.

Von Schirach, R. (2012). *Die Nacht der Physiker: Heisenberg, Hahn, Weizsäcker und die deutsche Bombe*. Berenberg, Berlin.

Wagner, C. S., Roessner, J. D., Bobb, K., Klein, J. T., Boyack, K. W., Keyton, J., Rafols, I., and Börner, K. (2011). Approaches to understanding and measuring interdisciplinary scientific research (IDR): A review of the literature. *Journal of Informetrics*, 5(1):14–26.

Waldinger, F. (2010). Quality matters: The expulsion of professors and the consequences for PhD student outcomes in Nazi Germany. *Journal of Political Economy*, 118(4):787–831.

Waldinger, F. (2012). Peer effects in science: Evidence from the dismissal of scientists in Nazi Germany. *Review of Economic Studies*, 79(2):838–861.

Waldinger, F. (2016). Bombs, brains, and science: The role of human and physical capital for the creation of scientific knowledge. *Review of Economics and Statistics*, 98(5):811–831.

Wang, J., Lee, Y. N., and Walsh, J. P. (2018). Funding model and creativity in science: Competitive versus block funding and status contingency effects. *Research Policy*, 47(6):1070–1083.

Wang, J., Veugelers, R., and Stephan, P. (2017). Bias against novelty in science: A cautionary tale for users of bibliometric indicators. *Research Policy*, 46(8):1416–1436.

Weingart, P. (2005). Impact of bibliometrics upon the science system: Inadvertent consequences? *Scientometrics*, 62(1):117–131.

Wenting, R. (2008). Spinoff dynamics and the spatial formation of the fashion design industry , 1858 - 2005. *Journal of Economic Geography*, 8(5):593–614.

Witt, U. (1993). Emergence and dissemination of innovations: some principles of evolutionary economics. In Day, R. and Chen, P., editors, *Non-linear Dynamics and evolutionary economics*. Oxford University Press, Oxford, UK.

Wray, K. B. (2004). An examination of the contributions of young scientists in new fields. *Scientometrics*, 61(1):117–128.

Yegros-Yegros, A., Rafols, I., and D'Este, P. (2015). Does interdisciplinary research lead to higher citation impact? the different effect of proximal and distal interdisciplinarity. *PLoS ONE*, 10(8).

Ziman, J. M. (1987). *Knowing Everything about Nothing: Specialization and Change in Research Careers*. Cambridge University Press, New York, NY.

Zucker, L. G., Darby, M. R., and Armstrong, J. S. (2002). Commercializing knowledge: University science, knowledge capture, and firm performance in biotechnology. *Management Science*, 48(1):138–153.