Innovation Modes in Small and Medium-sized Firms: Organization of Learning Processes and regional Innovation Policy Implications

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Tatjana Bennat, M. A.

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Referentin/Referent: Prof. Dr. rer. nat. Rolf Sternberg
Korreferentin/Korreferent: Prof. Dr. Kilian Bizer
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Abstract

Innovation is an important driver of economic growth. However, little is known about learning mechanisms by which innovation is created in firms with few formal research-and-development-structures, as is typical of small and medium-sized firms (SMEs). This dissertation aims to provide a detailed understanding of how innovation processes in SMEs are organized and how regional innovation policy in Germany might learn from these insights to better support innovation activities at their specific region. To achieve this overall goal, four research questions are guiding through this cumulative dissertation. First, it is asked what hinders combinatorial knowledge dynamics and second, which mechanisms are used to integrate STI-processes into DUI-mode learning routines. The third question includes which configuration of learning mechanisms leads to high innovativeness and, forth, how CEOs do influence innovation processes in SMEs. Accordingly, four articles are included, each of which is intended to address a different portion of this overarching aim. They explore the theoretical constructs of the knowledge base approach, the innovation mode concept, and the ideas of Regional Innovation Systems. The results are derived from mixed methods, being based on the quantitative data of occupation groups, qualitative interviews of SMEs, and regional innovation consultancies, as well as on quantitative data collected from the aforementioned interviews. The findings included several local factors that have hampered the combination of different knowledge types, and they identified obstacles that can only be overcome at the federal state level or the national level of Germany. Further, they highlighted that the integration of science-based knowledge into DUI routines should be understood as a continuum of combinations that vary in complexity. Mechanisms used to combine different innovation modes were described, and cognitive, organizational, and financial barriers that impeded combination were evaluated. However, a combination of STI and DUI is not the sole explanation of high innovativeness in SMEs. Rather, mere parts of the DUI mode, in combination with the STI mode, can explain high innovativeness. This has implications for managers as well as for innovation policy: different “recipes” for achieving high innovation exist. Finally, it is shown that the CEO acts as a particularly important moderator of and mediator between DUI learning mechanisms and innovation performance. This implies the importance of deepening innovation-policy offerings that strengthen an innovation-friendly cognitive base among CEOs who are able to integrate informal structures to accumulate their firms’ internal and external ideas. All insights described are applied to propose guidance for government policies in transferring theoretical insights into a contemporary, place-based policy approach.

Kurzzusammenfassung

Innovation ist ein wichtiger Motor des Wirtschaftswachstums. Dennoch mangelt es an Wissen über die Lernmechanismen zur Schaffung von Innovationen insbesondere in kleinen und mittelständischen Unternehmen (KMU), die keine explizite Forschung betreiben. Diese Dissertation soll detailliertere Einblicke ermöglichen, wie Innovationsprozesse in KMU in Deutschland organisiert sind und wie regionale Innovationspolitik effizienter helfen könnte diese zu unterstützen. Um das Forschungsziel zu erreichen, gliedert sich diese kumulative Dissertation in vier Forschungsfragen auf. Erstens, welche Barrieren bei der Kombination von unterschiedlichen Wissensarten bestehen und, zweitens, welche Mechanismen herangezogen werden um STI und DUI Prozesse zu verbinden. Drittens wird die Frage verfolgt, welche Konfiguration von Lernmechanismen zu besonders hoher Innovationsaktivität führt und viertens, welche Rolle dabei die Geschäftsführung spielt. Aufgegliedert in vier Artikel, werden verschiedene Aspekte des übergeordneten Ziels beantwortet. Theoretische Grundlagen sind der Ansatz der Wissensbasen und Innovationsmodi sowie Regionalen Innovationssysteme. Die Ergebnisse basieren auf einem Mixed Methods Design. Es wurden quantitative Daten von Berufsgruppen mit qualitativen Befragungen von KMU und regionalen Innovationsberater*innen kombiniert und quantitative Daten aus den Interviews abgeleitet. Die Ergebnisse umfassten mehrere lokale Faktoren, die die Kombination verschiedener Wissenstypen erschwert haben. Es zeigte sich, dass die Integration von wissenschaftlich fundiertem Wissen in DUI-Routinen als ein Kontinuum von Mechanismen zu verstehen ist, die sich in ihrer Komplexität unterscheiden. Ebenfalls wurden kognitive, organisatorische und finanzielle Hindernisse für eine Kombination hervorgehoben. Dennoch führte eine Kombination aus STI und DUI- Mechanismen nicht zwangsläufig zu einer hohen Innovationskraft von KMU. Vielmehr konnten nur Teilprozesse des DUI-Modus in Kombination mit dem STI-Modus eine hohe Innovationskraft belegen. Diese unterschiedlichen Erklärungswege halten (unternehmens-) politische Implikationen bereit. Schließlich wird gezeigt, dass die Unternehmensleitung als besonders wichtiger Moderator und Mediator zwischen den DUI-Lernmechanismen und der Innovationsleistung fungiert. Dies impliziert einen stärkeren Fokus innovationspolitischer Angebote auf die Bekräftigung eines innovationsfreundlichen Mind-Sets von CEOs, um unternehmensinterne und -externe Ideen für Verbesserungen und Neuerungen zuzulassen. Der Transfer dieser Ergebnisse in die angewandte Innovationspolitik wurde jeweils in den einzelnen Papieren als auch im Fazit der Dissertation abgeleitet und diskutiert.

Innovation modes, DUI, STI, regional innovation system, Innovation, Klein- und Mittelständische Unternehmen, Lernprozesse

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List of acronyms

DUI	Doing-, Using-, Interacting
STI	Science, Technology and Innovation
SME	Small and medium sized enterprise
e.g.	Exempli gratia (for example)
et al.	Et alii (and others)
LUH	Leibniz University Hannover
RICs	Regional Innovation Consultants
CEO	Chief Executive Officer
QCA	Qualitative Comparative Analysis
TTO	Technology Transfer Office
VET	vocational education and training

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1 Introduction

1.1 Innovation by SMEs and regional policy support perceived from an economic geography perspective

Where does innovation come from? One might think of universities, research-and-development (R&D) departments, or the laboratories of large firms. However, for small and medium-sized enterprises (SMEs) with between 1 and 250 employees, this picture might not fit snugly. Such firms do not often maintain formal innovation structures of these sorts - but does that mean they are not at all innovative? I argue that SMEs simply innovate differently than do larger firms, often making fewer (or no) explicit expenditures on R&D or dedicated R&D departments (Brink, Nielen & May-Strobl, 2018; Rammer, Czarnitzki & Spielkamp, 2009). Understanding how SMEs acquire knowledge and transfer it into innovation is critical to adjusting innovation policy to fit their needs (Aslesen & Pettersen, 2017; Coletti, 2010; Cooke, 2014; e.g. Isaksen & Karlsen, 2013). Since over 99% of firms in Germany are SMEs, they are an important policy target (Apanasovich, Alcalde Heras & Parrilli, 2016; Marchese, Giuliani, Salazar-Elena & Stone, 2019) as their ability to innovate is significantly connected to growth, competitiveness, and sustainability at the firm, regional and national levels (Apanasovich et al., 2016; Asheim, Boschma & Cooke, 2011; Tödtling, Lehner & Trippl, 2007). Thus, it is worthwhile to analyze how innovation processes unfold in SMEs.

For a long time, innovation-process theory was shaped by a linear model of invention, innovation, and distribution (Bush, 1945), implicitly emphasizing innovation as a result of science-driven knowledge (Lundvall & Johnson, 1994). Yet as far back as 1911, Schumpeter argued that various types of knowledge are important to innovation. Later, the innovation process was modified into a chain-linked model, portraying many feedback loops among users, researchers, and innovators (Kline & Rosenberg, 1986). This model implies that innovation need not be the result of science or R&D per se, but rather it can also be developed through experienced-based (Asheim & Coenen, 2005; Jensen, Johnson, Lorenz & Lundvall, 2007) and creative (Asheim & Hansen, 2009; Manniche, 2012) thinking. The ongoing trend of open innovation, the greater involvement of users, and the co-creation of ideas with firm-externals (Jensen et al., 2007)

highlight that innovation processes consist of combinatorial knowledge dynamics (Strambach & Klement, 2012).

This brief introduction points out that innovation is deeply connected with various knowledge types, their combination, and several learning processes, which all amount to an increasingly complex conceptualization of innovation. Considering this complexity, the underlying theoretical concept of this dissertation relies on insights brought forth by the knowledge base approach and the innovation mode concept combined with the regional innovation system approach and further developed with business management studies.

The knowledge base approach, introduced by Asheim and Gertler (2005), distinguishes between analytical, synthetical, and symbolic knowledge, which are together understood as the foundation of innovation (Asheim, Grillitsch & Trippl, 2017). While *analytical* knowledge, which is abstract and universal, is generated by searching and researching within universities, research institutions, and companies' R&D departments (Asheim et al., 2011), *synthetic* knowledge helps to construct context-specific, practical solutions to human problems through novel combinations of existing knowledge. *Symbolic* knowledge is developed through interactions with consumers or professional network players and involves open-ended, creative thinking that creates socio-cultural meanings, desires, and aesthetic qualities (Manniche, 2012). Manniche (2012) highlighted in particular that innovation consists of a combination of at least two knowledge bases. Accepting and extending this line of thinking, fostering combinatorial knowledge dynamics should be a pursuit worth engaging in. To generate implications, however, an analysis of practical barriers is first required. Nevertheless, existing insights fall short of answering questions about these barriers, which currently hamper the synthesis of knowledge bases.

The knowledge base approach also leaves room for the importance of different learning processes in creating various types of knowledge (Asheim, Coenen & Vang, 2007; Aslesen & Pettersen, 2017). These learning processes are stressed by Jensen et al. (2007), who differentiate between two ways by which learning processes result in innovation. On one hand is the learning-by-science, -technology and -innovation, the so-called "Science, Technology, and Innovation mode" (STI mode), and on the other, learning-by-doing, -using, and -interacting, the so-called "doing, using and interacting mode" (DUI mode) of innovation.

The STI mode is characterized by formal R&D processes, explicit scientific technical knowledge, and often-radical innovations. STI innovations are the result of scientifically trained workers and R&D investments (Isaksen & Trippl, 2017; Johnson, 2010); contrarily, the DUI mode refers to informal, non-R&D-driven learning processes, implicit experience-based knowledge, and incremental innovations. At its foundation, qualified and experienced workers, as well as organizational structures, foster employee participation (Apanasovich et al., 2016; Apanasovich, Alcalde-Heras & Parrilli, 2017; Jensen et al., 2007; Nunes & Lopes, 2015; Parrilli & Heras, 2016). While the STI mode is to a great extent covered by traditional innovation indicators such as patent data or R&D investment rates (Grillitsch, Schubert & Srholec, 2019), the DUI mode was handled in previous research as an abstract shell of innovation processes measured by diverse and interchangeable variables (Aslesen, Isaksen & Karlsen, 2012; Nunes & Lopes, 2015; Trippl, 2011; Trott & Simms, 2017), which is partially explicable by the holistic nature of the concept (Jensen et al., 2007). Although this dissertation does not introduce indicators for DUI-mode processes, such introduction was the overarching goal of the research project[1] of which this dissertation was part (see Alhusen et al., 2019). However, the insights—into the core mechanism of DUI-mode innovation processes—from which such indicators were derived serve as the basis of all four articles included herein. Definitions of the core mechanisms, which were developed during the research conducted for this project, are a) learning-by-doing as a result of work experience and increasing skills in production (Arrow, 1962; Thompson, 2010), b) learning-by-using as feedback from users and their involvement in improving products and services (Rosenberg, 1982), and c) learning-by-interacting as a product of interaction between firms, suppliers, and competitors, as well as other actors (Jensen et al., 2007; Lundvall, 1985).

[1] This work was part of the research project "InDUI – Innovationsindikatorik für den Doing-Using-Interacting-Mode von KMU" supported by the German Federal Ministry of Education and Research under Grant 16IFI005. The project was organized as a consortium of three partners: Georg-August Universität Göttingen together with the Institute of Small Business Economics (ifh) in Göttingen, the Friedrich Schiller Universität Jena and the Leibniz Universität Hannover.

In almost the same manner as research on combinatorial knowledge dynamics, several studies on innovation modes have argued that a mixture of both modes leads to superior innovation performance (Parrilli & Heras, 2016; Thomä & Zimmermann, 2019b). Nevertheless, a debate persists as to whether DUI and STI are complements or substitutes (Chen, Chen & Vanhaverbeke, 2011; Haus-Reve, Fitjar & Rodríguez-Pose, 2019; Thomä & Zimmermann, 2019a). This debate accompanies the research gap on learning mechanisms applied by SMEs trying to combine STI- and DUI-mode processes. Owing to their underlying knowledge base and a different ratio of learning processes and (thus) absorptive capacities, it might be difficult for SMEs to combine innovation modes (Bennat & Sternberg, 2020; Nunes & Lopes, 2015). Furthermore, little is known about the individual components of DUI-mode learning and whether these learning processes are equally relevant for innovation. Due to the inconclusiveness of DUI variables used, as well as differences in the measurements of innovation outputs, there is an absence of knowledge as to how and why SMEs combine innovation modes in practice and how they evaluate the importance of these processes to innovation. As a result, it is still unclear which is most promising for firms that seek to become highly innovative: DUI mode core mechanism alone, DUI in combination with STI, or STI processes alone.

In sum, the knowledge base and the innovation-mode approach both highlight that innovation is tied to knowledge-management processes (Nonaka & Takeuchi, 1995). Management researchers have reported that an organization's capacity to innovate is at least partially based on its ability to manage and utilize the formal and informal knowledge of its individual employees (Andries & Czarnitzki, 2014). In contrast, moderating and mediating factors of DUI-mode innovation processes have not, so far, been researched. Top executive roles in SMEs, in particular, could play an important role in innovation processes because it is these actors who make decisions about a firm's strategy, innovation projects, and openness to development and change (Hambrick & Mason, 1984; Obschonka & Stuetzer, 2017; Peterson, Smith, Martorana & Owens, 2003). Accordingly, knowledge of chief executive officers' (CEOs') influence on DUI-mode innovation would enrich both theory and practice concerning the surrounding factors in which DUI innovations take place.

It becomes apparent that innovation processes are complex, because micro-processes seem to influence each other. Nevertheless, theory and policymaking often neglect DUI-mode innovation, which may partly be explained by the focus of STI on innovation

measurement (Jensen et al., 2007; Laestadius, 1998). Manifestations of this argument are, for example, the trend of technology-transfer activities between universities and firms, the continuous improvement of R&D infrastructure, and the integration of STI processes as important policy goals into non-R&D firms (BMBF, 2018; Cooke, 2014; Isaksen & Karlsen, 2010). Additionally, state-financed regional innovation consultancies are important facilitators of DUI-mode innovation processes, giving advice for improving firm-internal processes, establishing connections with firm-externals, counseling during funding applications, and increasing firms' visibility (Alhusen et al., 2019). According to the Regional Innovation System (RIS) approach, a firm's regional economic structure, as well certain social and institutional factors, affect its learning processes (Asheim, 1996; Asheim & Coenen, 2005; Asheim, Grillitsch & Trippl, 2016, 2017; Cooke, Gomez Uranga & Etxebarria, 1997; Moodysson, Coenen & Asheim, 2008). Thus, from an economic geography perspective, exchange of formal and informal knowledge between private firms, government agencies, universities, and other public research entities is of great importance to innovation (Asheim et al., 2016). Hence, in line with the RIS approach, I assume that political authorities increasingly affect regional framework conditions for innovation (Asheim et al., 2016). Because each knowledge base and innovation mode has different policy needs, while historical and social structures differ across regions, regional innovation strategies should be customized and place-based (Martin & Trippl, 2014). Nevertheless, what this customization should look like in practice is an under-researched topic (Asheim, 1996; Martin & Trippl, 2014). In order to avoid an even more STI-mode-centric policy framework (Cooke, 2014), DUI-mode processes have been analyzed in detail in this dissertation, allowing the generation of policy implications that transcend the boundaries of the trend of technology-transfer activities and the continuous improvement of R&D infrastructure.

1.2 Objectives and Structure of this Dissertation

1.2.1 Research Questions

In accordance with the research gaps identified above, this dissertation faces four research questions, which could be all supplemented by the term " and what does that mean for regional innovation policy" as deriving policy implications is part of the overall goal of this dissertation:

I. What hinders combinatorial knowledge dynamics?
II. Which mechanisms are used to integrate STI processes into DUI-mode learning routines?
III. Which configuration of learning mechanisms leads to high innovativeness?
IV. How do CEOs influence innovation processes in SMEs?

The first research question focuses on barriers to combinatorial knowledge dynamics. Because former studies highlighted how important it is to innovation processes to combine different types of knowledge, it is merited now to study why combinatorial knowledge dynamics are hampered in practice. Further, if the combination of different knowledge types is promising for innovation, why does such combination rarely take place in practice? And what role does regional policy play in supporting these combinations? How could policy be adjusted to better support combinatorial innovation modes?

The second research question deepens the discussion about combinatorial innovation modes, which are more than the mere combination of knowledge types. It means the combination of microprocesses of each innovation mode. For example, the DUI mode contains processes of doing, using and interacting which in turn are characterised by several micro processes. Given the difficulty of finding any SME which did not combine processes of both modes, the questions of how and why SMEs engage with both processes becomes highly interesting. Which mechanisms are used to combine DUI and STI practices, and how do they differ from one another? Are they all equally restrained by barriers to combinatorial knowledge dynamics? Which policy lessons can we learn from these combinations of processes, and can innovation consultations provide help in combining innovation modes?

The third research question acknowledges the ongoing debate in innovation research surrounding how and why SMEs become highly innovative. Because former studies assume that combining DUI and STI processes increases a firm's level of innovativeness, I argue that it is valuable to break the DUI mode into its microprocesses of learning-by-doing, -using, and -interacting to discover whether each is necessary - or sufficient in itself - to explain high innovativeness in SMEs. Will high innovativeness always be explained by a combination with STI processes? Is it possible to become highly innovative by applying only DUI processes? What implications could this provide for managers and policymakers?

The fourth research question focuses on how, and through which personal characteristics, top executives influence innovation performance in non-R&D-based SMEs. Management studies have already highlighted the role played by CEOs of larger firms, which rely on formal STI processes and are thus functionally designed to produce innovation in R&D departments. But how innovative must a top executive of a non-R&D-based SME be if employee knowledge, customer ideas, and suppliers are at the core of that firm's DUI-mode innovation processes? Such firms are strongly reliant on internal and external knowledge exchange and employee participation in innovation projects during daily business operations. Thus, the CEO's ability to foster employee integration and interaction is critical for DUI-mode innovation in SMEs. It remains unclear, however, how and through what personal characteristics the CEO influences those innovation processes.

1.2.2 Research Objectives and Methodology

With this dissertation, I intend to provide a more detailed understanding of how innovation processes in small and medium-sized firms are organized, which barriers to combinatorial knowledge and innovation processes exist, and how regional innovation policy might help. With respect to the four research questions introduced in the previous section, I pursued four corresponding research objectives.

The first of these was to measure knowledge bases at the regional level, deducing practical barriers and evaluating which political level is responsible for producing solutions. Because each knowledge base differs in terms of its policy needs and demand for specific support from RIS (Asheim et al., 2016), regional innovation strategies must be tailored to specific regions (Martin & Trippl, 2014). Such tailoring is the basis of the smart specialization strategies advocated for by the European Union (2011) and the OECD (2011). Since less is known about its practical implementation, the first step that my co-author Rolf Sternberg[2] (Leibniz University Hannover) and I took was to measure regional knowledge bases using the employee knowledge base, operationalized by occupation groupings and a location quotient (LQ) analysis. The LQs of the 401 German NUTS-3 regions were adduced to select regions for a qualitative case study. The districts of Hanover Region and Goettingen district are similar regions in many ways, but the two differ in certain important aspects that could affect the process of innovation. Therefore,

[2] Please see the detailed co-author declaration explaining the differentiation of labour.

we would expect the two to be characterized by different barriers and, as a consequence, different political strategies of promoting knowledge exchange. In these sample regions, we conducted face-to-face interviews with 17 firm representatives and 16 regional innovation consultants. The transcripts of these interviews were used for content analysis. Qualitative content analysis systematically assesses transcripts by way of a theory-driven category system, which is developed, step by step, from the material. This category system contains deductive categories, which follow from theory and former research, as well as inductive categories, which contain novel information. Systematically deducing further categories in this fashion allowed us to be open to information that was not, in light of the existing literature and theory, anticipated. The process of defining the categories was initiated by coding 50% of the interviews, as suggested by Mayring (2010), and continued by a discussion of the category system among the research-team members. This discussion was used to define clear categories and coding rules. After the category system was revised in that way, all interviews were analyzed under it. This helped us to summarize the transcripts, explicate and structure aspects of importance, and answer the research questions (Mayring, 2010).

The second objective was to identify the various mechanisms used to combine innovation modes and evaluate them in terms of effectiveness, needed absorptive capacities, costs, and barriers. Little is known about internal changes in firms' learning routines or about the difficulties of combining innovation modes. Because of the mismatch between previous research, which argues that combining innovation modes leads to higher innovativeness, and my own position that combination is obstructed by several obstacles, we assume that a better understanding of the variety of mechanisms used by SMEs would enhance political support for SME innovation. Taking up the previous research objective, the underlying knowledge base, as well as the way in which knowledge is created and sustained, differs across innovation modes (Asheim et al., 2007; Aslesen & Pettersen, 2017). Therefore, it can be difficult for SMEs to achieve a combination of innovation modes (Bennat & Sternberg, 2020; Nunes & Lopes, 2015). To provide an enhanced understanding of firm innovation processes, the second article that my co-author Harm Alhusen[2] (University Goettingen) and I pursued, aims to analyse mechanisms used by SMEs to combine innovation modes at a micro level, as well as how this process can be

[2] Please see the detailed co-author declaration for the differentiation of labour.

supported by regional innovation policy. The set of exploratory interviews was expanded to include a total of 80, of which 49 were CEOs or managers of SMEs and 31 with regional innovation consultants, conducted in the three sample regions: Hanover, Goettingen, and East-Thuringia. Interviewees were asked to explain in detail how innovation with and without R&D activities takes place. The results are built on a qualitative content analysis of interviewee responses.

The third objective was to evaluate equifinal "recipes" for high innovativeness and compare the sampled regions in search of possible region-specific innovation practices. Insights into how SMEs acquire knowledge and transfer it into innovations is extremely important for adjusting innovation policy to fit the needs of SMEs (e.g. Isaksen and Karlsen, 2013; Coletti, 2010; Cooke, 2014; Aslesen and Pettersen, 2017). Thus, the third article sets its sights on showing that alternative explanations for high innovation performance exist. This insight reduces the risk of implementing putative "best practices" that do not fit a firm's setting. Further, this article proposes an alternative approach to measuring innovation activities, especially DUI processes, in SMEs, and it also makes suggestions for regional innovation policies in search of new instruments. Therefore, I divided the innovation mode concept into its core learning mechanisms (learning-by-doing, -using, and -interacting, and learning-by-science) and engaged in Qualitative Content Analysis (QCA) of 47 SMEs in the three sample regions. To the best of my knowledge, this method is applied in the innovation mode context for the first time. However, the QCA procedure relies eminently on the knowledge revealed by former content analysis of the interviews, as well as on a subsequent content analysis of the prototypical learning mechanisms meant to be identified by the QCA. I also tested for regional differences by qualitatively comparing the three sample regions in order to acknowledge regional specifics that would be significant for regional policymaking.

The fourth objective was to identify the role of CEOs and their specific characteristics in DUI-mode innovation processes in SMEs, which could improve the innovation mode concept by introducing insights from business management research. Because non-R&D-based SMEs innovate through more informal learning mechanisms, and often solely through a DUI mode, I argue that these processes are strongly influenced by such firms' top executives. This final article aims at shedding light on the role of CEOs and the influence of their characteristics on DUI-mode innovation processes. This inquiry is an important question because an SME's CEO strongly influences its ability to innovate,

which in turn influences growth, competitiveness, and sustainability. Using the transcribed interviews of 41 SMEs and 31 regional innovation consultants, I conducted content analysis (Mayring, 2010), relying on deductive categories for information related to our guideline questions and inductive categories for new information, such as details about the influence of top executives. CEOs' characteristics were inductively collected from CEOs' own answers, opinions, and the manner in which they organized or evaluated the innovation activities of their own firms. The contextual proximity of those characteristics and their influence on intra-firm learning mechanisms were visualized by the computer program MaxQDA, whose functionality allows for showing the closeness of codes.

To achieve transparency from whom a given piece of data was collected, I identify abstractions or statements sourced from SMEs with an "F" (firms) and those from regional innovation consultancies with a "C" (consultancies), appending the number of the interview, as per the internal database, to the appropriate letter (please see List of Interviews for complete case descriptions).

1.2.3 Description of Case Study Regions

The sample used to answer the research questions takes three German planning regions (*Raumordnungsregionen*) - Goettingen, Hanover, and East-Thuringia - as representatives of three different Regional Innovation Systems. Form an economic geography perspective this is important, as regional peculiarities could influence how and why SMEs organize their innovation activities. The first two of these regions belong to the federal state of Lower Saxony. The 16 federal states of Germany are important government actors, and consequently, significant aspects of policy-related governance were expected to be similar between Goettingen and Hanover. East-Thuringia belongs to the federal state of Thuringia, East Germany, and therefore sees alternative forms of government support. Universities and research centers are present in each of these regions, which allow for local cooperation with STI partners. All regions include metropolitan areas, which imply "organizationally thick" Regional Innovation Systems, but their economic structures assume different specializations (Isaksen & Trippl, 2017, S. 125), and they are characterized by a relatively high number of SMEs. Therefore, the regions are sufficiently similar to allow for comparison, but they differ in certain important aspects that could affect the process of using combinatorial innovation modes. The "Region Hanover," for

example, having three times as many inhabitants as Goettingen and almost twice as many as East-Thuringia, enjoys a higher density of potential contacts, which might be helpful for innovation. The City of Hanover is also the state capital of Lower Saxony and therefore hosts governmental innovation structures such as the state investment bank (Nbank), an innovation think tank (Innovationszentrum Niedersachsen), and a consultancy for digitalization (mitunsdigital). These institutions lead to greater availability of financial resources to support innovation in Hanover than in other two regions. Traditionally, Hanover has also presented a strong focus on academic engineering education and thus can be described by a "broad definition of RIS" (Isaksen & Karlsen, 2013, S. 247), including also a variety of facilitators supporting regional innovation activities.

This is also true for Goettingen, albeit that its universities and R&D institutes tend to be more involved in basic research. The Goettingen district is located in a structurally weak area of southern Lower Saxony, which is supported by the European Union's LEADER program and the *'Südniedersachsen Programm'*, a government program dedicated to revitalizing rural areas (Amt für regionale Landesentwicklung Braunschweig, 2014). In general, Goettingen is more concerned with demographic changes and a shortage of skilled workers than Hanover.

Both of these issues also plague East-Thuringia. Until the German reunification in 1990, Thuringia was part of the German Democratic Republic, which has led to the closures of large companies and a high unemployment rate, peaking in 2005. Nevertheless, the region profits from the science-rich, high-tech city of Jena. Close cooperation, based on the city's traditional optical-technology industry, between its internationally reputed universities and research institutes and the local SMEs is common (Industrie- und Handelskammer Ostthüringen zu Gera, n.d.). SMEs in Jena are often spin-offs of the local university and therefore more STI-orientated, matching a "narrow" RIS definition (Isaksen & Karlsen, 2013, S. 246). As a result, we expected more pronounced use of combinatorial innovation modes, as well as a different role of innovation consultancies, in East-Thuringia. Table 1 presents our sample of interviewees by region.

Table 1: Interviews by region

Target groups	**Goettingen**	**Hanover**	**East-Thuringia**	***Total***
Innovation consultants	10	12	9	*31*
SMEs	18	15	16	*49*
Total	*28*	*27*	*25*	*80*

1.2.4 Thesis Structure

This cumulative dissertation is organized into the four articles described above, which are preceded by this introduction and followed by a concluding chapter. Different from their emergence, the order of the four papers is structured by the idea to zoom in into firm internal activities and to deepen the questions the discussions of former findings brought forth.

Chapter 2 examines barriers to combinatorial knowledge dynamics. This is an important issue because greater involvement with users, as well as co-creation of ideas with suppliers or other firms, leads to innovation processes that are increasingly based upon combinatorial knowledge. Innovation is no longer restricted to R&D-driven, science-based knowledge; it is also the result of experiences and creative thinking. Operationalizing the knowledge base approach, this article clearly distinguishes between analytical knowledge, synthetic knowledge, and symbolic knowledge. The analysis of in-depth interviews brings forth several barriers that currently hamper combinatorial knowledge dynamics and categorizes them as solvable at the local, federal state, or national level. Showing that each knowledge type differs in terms of policy requirements, the aim of this paper is to guide government policies in transferring theoretical insights into a contemporary, place-based policy approach.

Chapter 3 deepens these insights into obstacles to combining knowledge types by focusing on SMEs' innovation processes and how SMEs combine different innovation modes. As the results of Chapter 2 show, combining different knowledge types, and thus innovation modes, can itself be an obstacle to innovation. However, analysis of the set of 80 exploratory interviews with SMEs and regional innovation consultants reveals that it is difficult to find firms that use the innovation processes of just one mode. Therefore, this article deduces the mechanisms through which firms combine the STI and DUI

modes of innovation. Results show that the innovation mode concept must be applied as a continuum of combinations. Thus, SMEs used a variety of mechanisms of differing levels of complexity to integrate STI-based knowledge into DUI routines. These mechanisms are discussed with regard to their effects on innovativeness, required absorptive capacities, and costs incurred. However, we also deduce cognitive, organizational, and financial barriers that impede a combination of innovation modes. According to the interviews with SMEs, regional innovation consultants can effect a successful combination, showing that policy support extends beyond financial services.

Chapter 4 is tied to the ongoing question in innovation studies of whether a combination of STI and DUI leads to high innovativeness. This picks up on the assumptions we followed in chapter 3, namely that the combination of both leads to higher innovation output. Acknowledging the holistic idea of the innovation mode concept, a QCA of 47 interviews with SMEs is applied to show that high innovativeness is based on a bundle of conditions, which are summarized as mechanisms of learning-by-doing, -using, and -interacting and learning-by-science. The results indicate that high innovativeness can be explained by the DUI mode alone or by portions of the DUI mode in combination with the STI mode. This result seems to be stable also at the regional level, implying, first, that there is no universal "best way" to become highly innovative and, second, that it is not more of everything that leads to high innovativeness. However, the presence of a learning mechanism alone does not force innovation. Rather, it enables a firm's agents to become involved with innovation processes. The interview analysis showed that innovation is also firmly determined by its agents, which is examined carefully in the next chapter.

Chapter 5 examines the influence of top executives on firm performance, including innovation activities, which seems to have a particularly magnifying effect on performance among SMEs, most of which innovate through a DUI mode. Traditionally, this mode lacks formal organizational structures for innovation activities; therefore, a CEO's capability and willingness to enhance employee commitment and integration takes on greater importance. I connect the DUI mode concept with business management research to answer the question of how, and through which characteristics, CEOs affect DUI-mode innovation activities. The results indicate that CEOs not only moderate DUI-mode learning processes but also mediate informal processes between DUI learning mechanisms and innovation performance. This refines theory concerning innovation processes in SMEs and suggests managerial and political implications: managers and

regional innovation consultants should focus on offers that strengthen an innovation-friendly cognitive base of CEOs who demonstrate appreciation of their firms' internal and external ideas.

Concluding remarks are made in Chapter 6. Summarizing the main findings in connection with the four research questions above, I reflect on the implications for researchers and policymakers. An outlook on further research is presented. Figure 1 provides an overview of the characterization of the four articles.

Figure 1: Characterization of the four articles

Article	**Knowledge bases in German regions: what hinders combinatorial knowledge dynamics and how regional innovation policies may help**	**Combinatorial innovation modes in SMEs: Mechanisms integrating STI processes into DUI-mode learning and the role of regional innovation policy**	**High innovativeness of SMEs and the configuration of learning-by-doing, -using, -interacting, and learning-by-science: a regional comparison applying Fuzzy Qualitative Comparative Analysis.**	**The underestimated role of top executives in DUI mode of innovation: CEO characteristics and their influence on innovation activities in non-R&D-based small and medium-sized enterprises.**
Focus	Barriers to combinatorial knowledge dynamics	Mechanisms of combinatorial innovation modes	Conditions for high innovativeness	Influence of CEOs in DUI-mode innovation processes
Objective	Measuring knowledge bases at the regional level, deducing practical barriers, and evaluating the level of government responsible for a solution	Identifying various mechanisms used to combine innovation modes and evaluating them in terms of effectiveness, capabilities, cost, and barriers	Evaluating equifinal "recipes" for high innovativeness and drawing a regional comparison	Identifying the role of CEOs and their specific characteristics in DUI-mode innovation processes
	Appraisal of the role of regional innovation policy			
Methods	Location quotient analysis + content analysis of 17 SMEs and 16 RICs	Content analysis of 49 SMEs and 31 RICs	QCA + content analysis of 47 SMEs	Content analysis of 41 SMEs and 31 RICs
Regional focus	Hanover and Goettingen	No regional differentiation	Hanover, Goettingen, and East Thuringia	No regional differentiation

2 Knowledge bases in German regions: what hinders combinatorial knowledge dynamics and how regional innovation policies may help

Authors: Tatjana Bennat & Rolf Sternberg

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Abstract

Due to the greater involvement of users and the co-creation of ideas with suppliers or other firms, innovation processes are increasingly based upon combinatorial knowledge. Thus, innovation is not restricted to research-and-development-driven, science-based knowledge, but is also the result of experiences and creative thinking. This has consequences for regional innovation policies because each knowledge type differs regarding policy requirements. Contributing to the under-researched topic of the barriers of combinatorial knowledge dynamics in practice, the aim of this paper was to guide government policies in transferring theoretical insights into a contemporary, place-based policy approach. In accordance with the knowledge base approach this paper clearly distinguishes between analytical knowledge, synthetic knowledge and symbolic knowledge. The analysis consists of in-depth interviews, conducted in two case-study regions in Germany. This paper deduces several local factors that have hampered combinatorial knowledge dynamics, and identifies obstacles that can only be overcome at the federal state or national levels.

Keywords: knowledge base, innovation, regional policy, combinatorial knowledge dynamics, Germany

2.1 Introduction

Innovative activities are the central determinant of national, regional or firm-specific competitiveness in modern knowledge-driven economies (Apanasovich et al., 2016; Asheim et al., 2011; Tödtling et al., 2007). In past decades, a great number of theories about its emergence and distribution, as well as empirical evidence, have been compiled (e.g. Asheim & Gertler, 2005; Fagerberg, Mowery & Nelson, 2005; Harhoff & Licht, 1993; Rammer et al., 2016). According to these innovation studies, the regional context plays an important role in innovation processes (e.g. Asheim, 1996; Asheim & Gertler, 2005; Bathelt, Malmberg & Maskell, 2004; Boschma, 2005), which can differ across regions. For a long time, the academic debate on regional innovation processes was determined by a linear model of invention, innovation and distribution (Bush, 1945). This interpretation of the innovation process implicitly stresses science-driven knowledge as a basis for innovation (Lundvall & Johnson, 1994).

According to Schumpeter (1911), different kinds of knowledge are important in innovation processes. Later studies modified the innovation process model into a chain-linked process, with many feedback loops among users, researchers and innovators (e.g. (Kline & Rosenberg, 1986). Such an interpretation of innovation processes implies that innovation is not restricted to research-and-development (R&D)-driven, science-based knowledge alone, but also includes experienced-based (Asheim & Coenen, 2005; Jensen et al., 2007) and creative thinking (Asheim & Hansen, 2009; Manniche, 2012). Due to the greater involvement of users and the co-creation of ideas with suppliers or other firms (Jensen et al., 2007), it has become obvious that innovation processes consist of combinatorial knowledge dynamics. Research on interactive learning processes has brought forth the idea that the exchange of knowledge among actors is crucial for the creation, use and transformation of knowledge into innovation (Strambach & Klement, 2012). Paradoxically, traditional innovation research has focused on technical innovation and indicators such as patent or R&D data, mostly resulting from science-based knowledge (Grillitsch et al., 2019).

In this paper, we have use the knowledge base approach, which makes a distinction between: i) analytical (science-based) knowledge; ii) synthetic (more experiential) knowledge to solve concrete problems; and iii) symbolic knowledge, which creates aesthetic values or designs (Asheim & Coenen, 2005; Asheim et al., 2007). Accordingly, this approach also makes room for innovation resulting from other knowledge dynamics,

and goes beyond the traditional innovation literature that focus on focusing on analytical knowledge (Grillitsch et al., 2019).

This idea of combining knowledge bases has consequences for regional innovation policies because each knowledge base differs regarding policy needs and the demand for a specific support from Regional Innovation System (RIS) (Asheim et al., 2016). It has become clear that regional innovation strategies need to be tailored to a specific region and its respective requirements, which necessarily reduces the relevance of 'best-practice models' for innovation policy (Martin & Trippl, 2014). In addition, this understanding is the basis of the smart specialization strategies advocated by the European Union (2011) and the OECD (2011). Even though this is a widespread argument, it is less clear how such a customized and place-based policy approach should look like in practice (Asheim, 1996; Martin & Trippl, 2014).

We know little about the practical implementation of combining different types of knowledge at the regional level, especially about the factors that hinder implementation. Contributing to the question in what manner combinatorial knowledge dynamics are hampered in practice, our aim was to guide political instances to transfer the theoretical insights into a contemporary place-based policy approach. We have used unique occupational micro-data from Germany to empirically operationalize the knowledge base approach and to enrich the analysis with in-depth interviews in two sample regions in order to uncover the perceived practical barriers to knowledge combination.

This article is organized as follows: in Section 2.2, we present the conceptual framework, building on the literature on knowledge bases and the role of policy in RISs. After an extensive explanation of the quantitative and qualitative research design in Section 2.3, the findings are reported and policy implications are discussed in Section 2.4. We draw some conclusions in the final section 2.5.

2.2 Theory of knowledge bases and the geography of innovation

2.2.1 The differentiated knowledge base approach

Since the globalization of the economy, knowledge processes have become increasingly complex. Hence, the dichotomy of tacit and codified knowledge, as well as the common distinction between high- and low-tech industries (Trippl, 2011), go not far enough when to deal with this complexity and to provide an adequate understanding of knowledge creation and its geographic distribution. The knowledge base approach relies on the

distinction between three forms of knowledge creation, which can be explained as the foundation of innovation (Asheim et al., 2017). Introduced by Asheim and Gertler (2005), the taxonomy explicitly integrates the output of interactions in innovation networks (Eder, 2018, S. 5).

Another advantage of the knowledge base approach is its 'epistemological' definition, distinguishing between how and through whom knowledge is created, and to which value and field of application the knowledge is attributed (Manniche, 2012). The knowledge base approach defines three modes of learning and knowledge creation, as well as the ensuing knowledge types (Manniche, 2012). It differentiates between analytical, synthetic and symbolic knowledge creation, although overlaps between these three knowledge types exist (Martin & Moodysson, 2013).

The purpose of *analytical* knowledge generation is to theoretically understand the natural or social world, to test scientific laws or to establish new ones (Asheim et al., 2017). Generated by searching and researching in epistemic communities, it typically occurs at universities, research institutions and R&D departments of companies (Asheim et al., 2011). Such knowledge is highly abstract, universal and, as a result of the documentation, to a large extent codified and therefore transferable over distance (Manniche, 2012).

Contrary to that knowledge base, the purpose of *synthetic* knowledge creation is to design or construct context-specific, practical solutions to human problems. The creation process accrues through novel combinations of existing knowledge, and is due to intra-firm learning by doing, by using or by interacting with costumers or suppliers (Jensen et al., 2007). It is mostly tacit, context- and practice-specific, but has also some codified components that make it partly mobile across space and sectors (Asheim et al., 2017; Manniche, 2012).

Finally, *symbolic* knowledge is generated with the purpose of creating socio-cultural meanings, desires and aesthetic qualities. It occurs through interaction with consumers or professional network players, and involves open-ended, creative thinking and the combination or reinterpretation of established conventions and expertise in art, design or marketing (Manniche, 2012). Conditioned by its specific socio-cultural context, symbolic knowledge has a mostly tacit character that makes it difficult to transfer across space (Asheim & Hansen, 2009). However, being tied to daily-life culture and the local buzz, it benefits from cross-fertilisation from overarching professions and sectors (Manniche & Testa, 2010).

Therefore, distinction among the knowledge bases means that innovation does not only occur through learning by searching and researching, but also through learning by doing, using and interacting. (Jensen et al., 2007) enumerated these two fundamental learning and innovation modes as the 'Science, Technology and Innovation-mode" (STI-mode) and the 'Doing, Using and Interacting-mode' (DUI-mode). The STI-mode is characterised by formal R&D processes, explicit scientific technical knowledge and often radical innovations, whereas the DUI-mode refers to informal, non-R&D-driven learning processes, implicit experience-based knowledge and incremental innovations.

2.2.2 The role of policy in regional innovation (systems)

Following the literature on knowledge dynamics, the specific knowledge base of actors, their competencies or capabilities, and the geographic context play an important role for how these processes take place (Strambach & Klement, 2012). Building upon the notion that innovation stems from complex, interactive and cumulative learning processes, while involving a variety of actors (Asheim et al., 2016), it has been broadly stated that knowledge generation is driven by unique regional framework conditions (Boschma, (2005). These regional framework conditions have been and are, with an increasing tendency, designed by political authorities to create competitive advantages (Martin, Moodysson & Zukauskaite, 2011). While patterns of competitive advantages are constantly changing, regional policy-makers are engaged in promoting and supporting interactive learning, and hence regional cooperation (Martin et al., 2011).

This argument is in line with the RIS approach and its systemic perspective relying on the perceptions of the importance of geographic proximity for knowledge exchange and learning dynamics, as well as its regional governance structure (Asheim et al., 2016). Accordingly, the RIS has to consider the regional economic, social and institutional factors affecting the firm's learning processes. It highlights the formal and informal cooperation of private firms, governmental agencies, universities and other public research entities (Asheim et al., 2016). Bathelt et al. (2004) stated that informal links are prevalent at the regional level, while formal links are found more often on the (inter-) national level. It has become clear that knowledge dynamics are not only located regionally, but that also global knowledge sources play an important role in innovation processes. This regional and national knowledge infrastructure influences the absorptive capacity of the actors in innovation systems (Asheim et al., 2016). Therefore,

competitiveness in the knowledge economy is tied to the configuration of an innovation system, its openness, and a combination of regional and global innovation networks. This might become true especially for an analytical knowledge base, but also for synthetic and symbolic knowledge networks, although with different weights.

The RIS approach highlights the role of regional policy in innovation. In order to choose productive, tailor-made support strategies, political instances have to recognize the existing regional innovation structure (Martin et al., 2011) and how this has been shaped by history (Asheim et al., 2011). Focusing only on analytical knowledge, as traditional innovation indicators do, the regional structures of other knowledge and learning types are faded out in the analysis and support of regional framework conditions for innovation. In our paper, consequently we have used the differentiated knowledge base approach to measure the geography of different knowledge types as a basis for subsequent qualitative analysis.

2.2.3 How the existing literature contributes to a place-based policy approach

Aiming at fine-tuned recommendations for regional innovation policy, it is crucial to determine the regional, i.e. subnational, conditions of knowledge dynamics (Martin, 2012). The knowledge base approach has been applied by a number of scholars, and refined as a useful heuristic for analysing RISs (Asheim & Coenen, 2005; Coenen & Moodysson, 2009; Moodysson et al., 2008). Inspired by the early work of Asheim und Hansen (2009), Martin (2012) developed a quantitative operationalisation for measuring the geographical distribution of the three knowledge bases in Swedish regions in order to allow for interregional comparison. The study demonstrated that regions differ in the way they are specialised, and that most regions are dominated by one type of knowledge base, although some regions are specialised in more than one knowledge type (Martin, 2012). The key advantage of this method was its openness to emerging and transforming industries crossing traditional product classifications (Grillitsch, Martin & Srholec, 2017).

Underpinning the argument that a combination of different types of knowledge is favourable for innovation and economic growth, the research team of the EURODITE project, funded by the European Commission, investigated how knowledge is generated, developed and transferred within and among firms or organisations (Halkier, James,

Dahlström & Manniche, 2012). For example, Manniche (2012) analyzed 52 innovation biographies of European firms, discovering that only two innovations were related to just one knowledge base. The other 50 innovations combined at least two knowledge bases during the learning process of the specific innovation. The EURODITE team considered the innovation processes of new products, new technologies and new organisational infrastructures, realising that each knowledge base was equally important for the development of the innovation (Manniche, 2012). Consequently, regional innovation policy should take into account that the way of developing, using and diffusing knowledge varies between the three knowledge bases, and should ensure an efficient learning environment and the possibility of exchanging knowledge across institutional borders (Manniche, 2012). Strambach und Klement (2012) evaluated individual knowledge interactions, finding that cumulative knowledge interactions within the same knowledge base were typical for subsequences of innovation. This highlights that knowledge exchange within *and* between knowledge bases is crucial for the development of innovation.

The same study shows that no single innovation biography was restricted to just one location and region. Although intra-regional interaction was more frequent, national or international interactions were important in obtaining specific knowledge that was not available in the home region (Strambach & Klement, 2012). Hence, regional innovation policy-makers should be aware that cumulative knowledge bases open windows of opportunity for combinatorial knowledge dynamics at the non-regional level as well. Strambach and Klement (2012) concluded that the involvement of a variety of actors, originating in different technological, sectoral and regional contexts, is typical of combinatorial knowledge dynamics. Cooke (2012) pointed in the same direction, finding a shift from vertical, cumulative and sectoral-specific knowledge interactions to horizontal and combinatorial exchange. Thus, interactive learning processes tend to be cross-sectoral, reaching beyond qualifications. Indeed, these findings still show little impact on policy-making practices (James, 2012). These changes in learning processes have to be recognised and implemented by regional innovation policies. This is especially true for the integration of symbolic knowledge dynamics, which traditionally have not belonged to the core activities of fostering knowledge exchange (Halkier et al., 2012). Hence, the RIS concept should be extended by the integration of demand and cultural trends in civil society. This implies, at the same time, that regional innovation policy

should be supplemented by competences of integrating different types of knowledge (Halkier et al., 2012).

There are also several quantitative studies investigating the dependence of combinatorial knowledge and innovation performance. Firms obviously source knowledge from all geographic scales, and are more innovative if combining different knowledge bases (Tödtling & Grillitsch, 2015). Grillitsch et al. (2017) showed that firms are more innovative in regions with a balanced configuration of analytical, synthetic and symbolic knowledge. Nevertheless, this should not end in the political argument of 'more of everything'; instead, the authors advised working on tailor-made specialisation strategies (Grillitsch et al., 2017). This was confirmed by Eder (2018), who inferred a close cooperation of firms and policy-makers to meet specific regional demands. Regions with a strong analytical knowledge base might benefit from interaction with universities outside the region, if the knowledge generation institutions are not available in the home region. On the other hand, regions with a high amount of synthetic knowledge base might rather profit from subsidiaries for on-the-job training programmes. Therefore, new policy approaches should overcome traditional cluster policies and move towards platform policies (Asheim et al., 2011; Cooke, 2012), comprehending that the dichotomy of core and peripheral regions comes short in describing the regional innovation and learning processes (Eder, 2018). Summarising the existing literature, it becomes clear that there is a vast amount of regional innovation policy advice, but less about the practical implementation of those theoretical and empirical findings.

As the review demonstrates the knowledge base literature developed from a static and descriptive view of knowledge bases to a combinatorial understanding, which is also more connected to approaches of evolutionary economic geography (Boschma, 2018). Focusing on the combinations between and within knowledge bases, and whether these provide similar or complementary learning resources and enhance innovation opportunities (Boschma, 2018), such more recent approaches merge concepts like relatedness, cognitive proximity and related variety (Frenken, van Oort & Verburg, 2007) with the knowledge base approach (Quatraro, 2010, 2016). Protagonists of evolutionary economic geography argue, that because of different capabilities and uncertainties, actors prefer to interact with local partners (geographic proximity) who have a similar knowledge base (cognitive proximity), share the same norms and values (institutional proximity), social ties (social proximity) or organisational arrangements (organisational

proximity) (Boschma, 2018; Ponds, van Oort & Frenken, 2007). Considering that we choose regions as case-studies, we theoretically expected barriers of combinatorial knowledge dynamics due to the dimensions of cognitive, social, institutional and organisational proximity, while geographical proximity is inherently given by research design. Nevertheless, as Grillitsch, Asheim und Trippl (2018) had shown there is potential of unrelated knowledge combination for regional industrial path development. They state, that unrelated variety refers to the combination of knowledge between knowledge bases and is the source of most radical forms of path creation, diversification and upgrading. Highlighting regional framework conditions and its key role for anchoring new industries and economic growth, they encouraged regional policy to develop supportive industries, skilled labour force and innovation and growth friendly institutions (Grillitsch et al., 2018). With respect to the political influence of the related variety concept, we also suppose a stronger interest of political instances in connecting partners within one knowledge base and less intention for cross-knowledge base interactions.

In applying the knowledge base approach to German regions, we intend to provide responses to the question of how a place-based policy approach should look in detail. Hence, we focused on an implementation of the insights the knowledge base research of the last 10 years has brought forth to the practical regional innovation policy in Germany.

The main questions addressed in this paper are thus: (1) how and why are combinatorial knowledge dynamics hampered in practice; and (2) how can this concept contribute to the fine-tuning of regional innovation policy?

2.3 Methods and data

For this study we chose a mixture of quantitative and qualitative research methods. While case studies are an insightful tool for analysing RISs and the complex generation of new knowledge and its spillovers, a quantitative research design can provide opportunities for interregional comparison and can help to identify the knowledge specialisation of a region (Martin, 2012).

Inspired by Asheim und Hansen (2009), Martin (2012) and Grillitsch et al. (2017), we first used the knowledge base of employees to measure the knowledge base of a region. For this, we used the three-digit occupation groupings of the German classification of

occupations from 2010[3]. Occupational data reflects the activities or tasks that employees have undertaken, and, therefore, they implicitly show the knowledge the employees need to do their jobs. The advantage is that employees who transact the same tasks are classified into the same group, taking no account of the industry they belong to (Martin, 2012). Hence, occupational data is more appropriate to capture an individual knowledge base than educational data (which does not take career progress into account) or patent statistics (which do not capture innovations resulting from symbolic knowledge) (Grillitsch et al., 2017). Occupational data has recently been successfully used for empirical research to detect spatial patterns of German regions regarding Florida's creative class (Vossen, Sternberg & Alfken, 2019) and the effect of digitisation on employment (Wrobel, Buch & Dengler, 2016).

To uncover the regional specialisation in a knowledge base, we applied regionally-aggregated occupational data from June 2017 at the district level (NUTS-3), and used a location quotient (LQ) analysis. The LQ analysis compares the presence of particular occupations or, to be precise, the knowledge bases in a region, with the national knowledge specialisation (Martin, 2013). If the LQ is above 1, this indicates that the share of the knowledge base is higher than the national share, whilst values below 1 stand for a share below the national average (Martin, 2013). Further, we considered a LQ above 1 plus the standard deviation of each knowledge base to be a strong concentration and a LQ less than 1 minus the standard deviation to be a weak appearance.

The results of the regional comparison of the 401 German NUTS-3 regions were adduced to select regions for a qualitative case study, in order to detect factors that hindered exchange among the three knowledge bases. By selecting two regions with different specialisation patterns regarding knowledge bases, we kept the research open to different barriers of combinatorial knowledge exchange that this specialisation could include. Hence, we chose the Region of Hanover and the Goettingen district as our in-depth case studies. Both regions have in common that they belong to the federal state of Lower Saxony and, given the federal system in Germany with the 16 federal states being very important government actors, significant parts of the policy-related governance should have been similar. Also, large universities and research centres are located in both

[3] For further information about the matching of occupation groups and knowledge bases see appendix II)

regions, which allows local cooperation with the analytical knowledge base. This exchange is supported by technology transfer offices at universities in both regions (Hesse & Sternberg, 2017). Entrepreneurs and firms can claim different local innovation consultancies or innovation networks, or use co-working spaces provided in both cities (e.g. hannoverimplus, Hafven, Lower Saxony Innovation Campus 'SNIC', Gründungsförderung GAUG; e.g. Backhaus, 2000). They also provide a network for the creative and cultural economy (e.g. KreHtiv, Stellwerk; see Stüting, 2016), thus showing that both regions offered several promotion structures for each of the three knowledge bases. Further information about the two regions is provided in Table 2.

Table 2: Regional comparison of the Region of Hanover and of the Goettingen district

	Goettingen district	Region of Hanover
Inhabitants (no.)	328,036	1,152,675
Population density (inhabitants/km)	187	502
Employees covered by social insurance (no.)	127,748	499,479
Unemployment rate	5.3	6.2
Economic structure (employees in %)		
Agricultural, Forestry and Fishery	0.93	0.54
Manufacturing industry	20.74	16.79
Service industries	78.34	82.67
Students (no.)	35,750	49,993
(Bundesamt für Arbeit, 2018; Statistisches Bundesamt, 2018)		

The Region of Hanover and the Goettingen district differ in important details, however. For the Region of Hanover, the LQ of the three knowledge bases is close to 1, which indicates an average share compared with the rest of Germany. Therefore, the potential to combine the different knowledge bases should also be close to the national average, which implies that the discovered barriers could also be transferred to other regions with an average share of each of the three types of knowledge. In the Goettingen district, the LQ of the analytical knowledge base is above the national average, the synthetic below average and the symbolic is about the average (see Table 3). Hence, we assumed different

barriers to combinatorial knowledge dynamics from the two regions. The differences are also noticeable when analysing the absolute and relative share of workers for each knowledge base. In Goettingen district the relative share of workers with an analytical knowledge base is nearly twice as high as in the Region of Hanover whereas the share of synthetic knowledge base is slightly lower in Goettingen. The share of the symbolic knowledge base is almost the same in both regions. Nevertheless, the absolute and relative share of the symbolic knowledge base is extremely small. Hence, we assume that in both regions actors face the same difficulty to get in contact with a symbolic knowledge base, since it covers only a small proportion of the labour force. Further, we presume that this small share of symbolic knowledge fades into obscurity by regional innovation consultancies because they are less kept in sight of their daily work.

In addition, the Region of Hanover has more than 3.5 times more inhabitants than the Goettingen district. Being the state capital of Lower Saxony, Hanover city is the location of innovation infrastructure provided by the federal state, such as the investment bank NBANK, the innovation think tank 'Innovationszentrum Niedersachsen' of the Lower Saxony government and a consultancy for digitisation 'mitunsdigital'. Hence, the Region of Hanover has more financial resources and a higher density of potential contacts, which might be helpful for innovation. The Goettingen district is the most southerly region in Lower Saxony, located in a structurally weak area and supported by the European Union LEADER programme and the 'Südniedersachsen Programm', a specific Government programme to revitalise rural areas in the southern part of Lower Saxony (Amt für regionale Landesentwicklung Braunschweig, 2014). In brief, the Goettingen district is more affected by demographic change and shortage of skilled workers than the Region of Hanover. Also, the regions differ in their focus on research and academic disciplines. Most students in Hanover study engineering or business science, whereas in Goettingen, law, business and social science are the most chosen subjects (Region & Landeshauptstadt Hannover, 2020; Stadt Göttingen, 2020a)

Therefore, the two regions are similar in many ways, but differ in certain important aspects that could affect the process of innovation. Bearing this in mind, we would expect to find different political strategies to promote knowledge exchange and, as a consequence, different aspects that hampered combinatorial knowledge dynamics.

We thus conducted face-to-face interviews with 17 firm representatives and 16 regional innovation consultants or local business development agencies ('Wirtschaftsförderung')

that were concerned with building up knowledge networks and increasing absorptive capacities in regional small and medium-sized enterprises (SMEs) (Table 3). While the questions were derived from previous theoretical and empirical contributions, the interviews consisted of open questions (Flick, 2017). Anonymity was ensured to all interviewees. The interviews were recorded and transcribed afterwards. Using those transcriptions, a coding procedure was conducted to analyze the qualitative evidence. Using the software program MaxQDA, we followed the method of content analysis (Mayring, 2010), thus incrementally reducing the content of the interviews to those statements relevant to our research questions. To achieve this, open codings were developed first, which led to further condensed and detailed codings, which could be assigned to more nuanced categories and subcategories. Those, in turn, were used for the analysis, upon which the results were built.

Table 3: Location quotients and number of interviewees in both case-study regions

Nuts 3 Region		Knowledge bases			No. of interviewees	
		analytic	synthetic	symbolic	SME	Innovation Consultants
Goettingen district	Location quotients by knowledge bases*	Above-average (1.924)	Below-average (0.931)	On-average (0.785)	8	8
	Share of employees (total number of employees)	14.29% (15,698)	83.28% (91,494)	2.43% (2,673)		
Region of Hanover	Location quotients by knowledge bases*	On-average (1.153)	On-average (0.989)	On-average (1.046)	9	8
	Share of employees (total number of employees)	8.56% (38,111)	88.20% (392,707)	3.24% (14,437)		

* LQ > 1 plus standard deviation of each knowledge base = Above-average concentration
LQ < 1 minus standard deviation = Below-average concentration (for precise values of the averages and more information see appendix II)

2.4 Results

2.4.1 Barriers to combinatorial knowledge dynamics

Our qualitative data analysis on how combinatorial knowledge dynamics are hampered in practice in the two regions of Goettingen and Hanover shows, that such barriers can be aggregated into eight topics, which are addressed below (see appendix II).

First, the *perception of potential for combinatorial knowledge dynamics* varies between the two regions. The Region of Hanover was highlighted as 'being a good place for interdisciplinary work because of the great mixture' of knowledge bases (C14), which is in line with the LQs we derived (see Table 3 again). In Goettingen, technology transfer between SMEs, focused on synthetic knowledge, and research institutions, producing primarily analytical knowledge, 'plays a crucial role'. Such a transfer, for example, takes place on the Innovation Campus SNIC (C4), while the symbolic knowledge base 'does not attract much attention' (C9), which is not in line with the LQs (the synthetic knowledge base was below average, symbolic average and analytical above average).

Interviewees both in Goettingen and in Hanover criticised the universities for not exercising their third mission, and for being unaware of their regional role related to skilled workers. According to the interviewees, the research strategies of the universities were hardly influenced by the regional demands of the firms. For Goettingen in particular, the open up for regional companies had only been happening over the last seven years. As there are no creative study programs, the production of symbolic knowledge in an academic context and 'the formalised education of creative occupations is less important for Goettingen district' (C9).

The interviewees in the Region of Hanover assessed that 'there is a general trend of being more open to new ideas and knowledge from related sectors' (F25). Not only incremental product and process innovations are important for SMEs, 'but also organisational innovations. This is in hand with innovation methods like design thinking, scrum and agile business' (C20).

Second, almost all of the interviewees stated that cross-sectoral knowledge and interdisciplinary teams were important conditions for being innovative, thus showing an *interest in different knowledge*. It was noticeable that the interviewees in both regions first explained their motivation to cooperate with universities or other firms within the *same* knowledge base that belonged to other industries. Most of the firms used university

cooperation ‘for recruiting skilled labour’ (F20) and for ‘testing prototypes or optimising technical processes’ (C4). In particular, cooperation with universities of applied sciences proved to be helpful and practically relevant. According to the interviewees, the most frequently named barrier was that universities only do basic research without practical relevance. The SMEs and innovation consultancies indicated that there was no agreement about the scientific questions and daily problems the SMEs have to deal with. This is especially true for craftsmanship because this sector has benefitted from the current prosperous economic situation. This has led to a surplus of orders keeping workers from innovation activities. Moreover, the missing practical experience of students was highlighted. Thus, even the support of theses was time-consuming for the SME. Further, the high employee turnover at universities impeded knowledge exchange. It was also remarked that universities do not foster interdisciplinary knowledge exchange, and that ‘co-working spaces in universities are always intra-faculty’ (C18). The opinion is widespread that analytical and symbolic knowledge are irrelevant for SMEs with a mostly synthetic knowledge base, even among those SMEs that have already been involved in some research cooperation in the past.

Only a few interviewees stated motivations for cooperation with firms in the symbolic knowledge base. Actually, several of the firms had no experience with symbolic knowledge exchange at all, stating that they assigned external partners for creative tasks. Hence, many of the following barriers for cooperating with the symbolic knowledge base occurred through prejudices. The interviewees considered that ideas from a symbolic knowledge base were not practically relevant and also raised costs. This ended in the dissatisfaction of the customers. The firm representatives explained that symbolic services providers even submitted traditional solutions, and therefore stronger co-working would be inefficient.

Third, the (project) structure seemed to hamper combinatorial knowledge interaction. In particular, the *duration* of cooperation was criticized by both groups of interviewees. They claimed that the universities were too rigid and administrative, with impenetrable hierarchies, which created long decision-making processes, whereas SMEs – and start-ups in particular – were considered to be very agile and sometimes did not survive for these extended intervals of time. Looking for quick, practical solutions under high, competitive pressure, SMEs tend to be impatient. Some interviewees stated that there was a general lack of time for cooperation with research institutes. One interviewee of a SME

noted that ‘particularly applied science professors, who should be more practically orientated, per se, have a lack of time for cooperation because many of them are also CEOs’ (F18). Some regional consultants described that traditional business structures (especially in medium-sized enterprises) hampered the exchange of creative knowledge because the business units kept pushing themselves forward. Knowledge exchange was not fostered at all because of lack of time.

Fourth, according to the regional innovation consultants, SMEs do not recognise the benefit of the *outcomes of cooperation* because, after the cooperation period, they have to invest time and knowledge to implement the results and to get the new product or process ready for the market. Further, implementation on their own deterred SMEs from cooperating with universities or using symbolic creative methods, such as design thinking. ‘These methods tend to get self-iconic, which increases refusal, in turn’ (F20). In addition, the consultants observed that, especially in old or traditional industries, no culture of innovation existed that was open to such methods. Likewise, these techniques were not as easily implemented as the managers would have wished. It was also explained that technology transfer with the universities was not done in dialogue with the company, so no real collaboration existed, and therefore the research results could not be used in practice.

Fifth, conflicts about *publishing* findings hampered knowledge exchange. While SMEs in the synthetic or symbolic knowledge base were interested in confidentiality, research institutes wanted to publish the new knowledge or save it through patents or licenses. SMEs were simultaneously overwhelmed with license negotiations or regulations for the further use of the results in subsequent projects, while the firms were no longer involved. This, in turn, reduced the motivation for cooperation.

Sixth, another impediment that was noted by the regional innovation consultants was a *psychological barrier* for SMEs in contacting R&D institutes. Being ‘frightened’ by professors and their high levels of knowledge, ‘especially as craftsmen’ (C6; C4), doomed potential collaborations with universities. In contrast, the SMEs neither addressed nor denied this psychological barrier (F18). In the case of symbolic cooperation, CEOs who did not delegate authority hampered the combination of different knowledge bases. This is in line with the argument that thinking in terms of hierarchy obstructs the exchange of creative knowledge. Also, low self-confidence for combining different knowledge and ideas reduced the motivation to collaborate with other knowledge bases.

Seventh, in cases where a SME was motivated to collaborate with a university, finding the *right contact person* was compounded by the fact that, in Lower Saxony, the federal state of both case study regions, 'no research project-database exists' (C21). SMEs took advantage of personal contacts with professors or research associates. These contacts were often extra-regional, and therefore accompanied by higher transaction costs. Even if the knowledge was also available in the region, they preferred their former contacts simply because they did not know that there was a specialist right next door. Also, universities do not know all companies in their region, and so they have implemented technology transfer offices (TTOs). However, due to limited financial resources, the TTOs do not respond to every request, and they also do not know about already existing cooperation. This results in a rather low level of technology transfer in practice and 'just selecting contacts the SME could also find on their own' (C21). This highlights the importance of facilitators to bring different knowledge bases together. However, one private innovation consultant explained that consultants of 'the office of economic development advises 'New Work'[4], while they themselves work in traditional structures, ending in lost credibility' (C20).

The support of the cultural and creative industry was also recently added to the agenda. The interviewees in Goettingen criticised the strategies of knowledge exchange as being very outmoded, and that 'a platform is missing where firms can come together' with creatives (F6). 'While a formalised TTO and industry network exists, occupations based on symbolic knowledge are not involved. However, the creatives in Goettingen district do not plug into the promotion that already exists in the region' (C9).

Eighth, *financing* a collaboration played a crucial role. 'The project budget required by the universities is often around €100 000, while the SME requirement is covered by around €10 000' (C16). It was also stated that, after the division of grants, there was only a small amount of money left for the institute itself, which in turn reduced the motivation of the professors to collaborate. Generally, the SMEs were overwhelmed with document duties, and were not motivated to apply for EU-funded projects because of the high rejection rate. It was also observed that SMEs with less than 10 employees had no chance to participate in projects of the Zentrales Innovationsprogramm Mittelstand (ZIM, nation-

4 'New Work' describes the change in labour structure, the importance of the work/life balance and the power structure see e.g. Corporate Alchemists (2018).

wide innovation program for medium-sized enterprises) funded by the Federal Ministry for Economic Affairs and Energy because they could not spare employees from their daily business for the required amount of time. The fact that R&D institutes may receive a 100% support, but SMEs would have to co-finance 50%, does also reduce motivation. Equally, the combination with symbolic knowledge was declared to be too expensive.

2.4.2 Implications for innovation policy

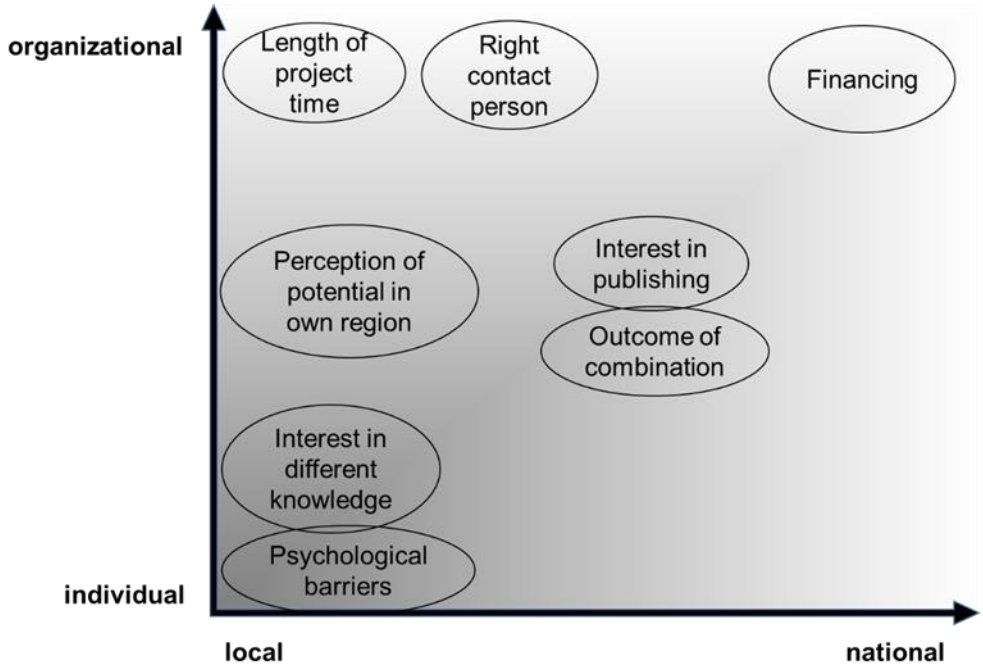
In order to answer the second research question (how this concept can contribute to the fine-tuning of regional innovation policy), we discuss our findings below, with respect to the literature (see also Section 2.2).

Using a mixed methods research design, our findings confirm this as a useful method for comparing regions in a mathematical manner on the one hand, and for fleshing out these results with non-measurable aspects relevant to improving policy strategies on the other. Comparing our procedure with previous studies using occupational data, we found similarities in the case of symbolic-knowledge-based occupations and the bohemian group of the creative class (see Vossen et al. 2019). We also observed similar regional patterns for patents (Deutsches Patent- und Markenamt, 2018) and analytical knowledge, indicating that the recent attribution among certain occupations and the symbolic and analytic knowledge bases is valid. In the case of synthetic knowledge, we did not find any indicator that measures innovation from this type of learning. Therefore, more research is needed. None of the 401 districts shows below average LQ for each of the three knowledges bases. The same is true for above average LQs. However, nearly half of the districts is characterised by average values for each of the three knowledge bases. These results differ from the findings of Martin (2012), who showed that most Swedish regions are dominated by one knowledge base.

This comparison qualifies every region with development potential, regardless of whether it is located in a core or peripheral region. Government support strategies should therefore consider the different needs of each knowledge base, how this knowledge is created and how innovation processes are shaped by a specific knowledge base. In any case, the regional potential of combining different knowledge bases also depends on the absolute concentration of employees (critical mass), as well as the geography of knowledge bases in adjacent regions. These aspects have to be considered in regional innovation policy strategies.

Arguments of evolutionary economic geography (see Boschma, 2005) and our expectations about organisational boundaries and cognitive distance between innovation actors within a region may lead to an underestimation of the opportunities of combinatorial knowledge. Our empirical results, however, show that this is only one part of the story. On the one hand our case study areas are characterized by some strong organisational barriers hampering innovation processes, for example between SMEs and universities located in the region, and these perceived barriers do indeed limit the ability and willingness to combine knowledge bases. Also, cognitive distances between several innovation actors in each region are far from zero, and negative effects on the volume of combinatorial knowledge were observed. On the other hand, our empirical results revealed that other than the two arguments presented before were more influential when to explain the limited amount of combinatorial knowledge. In particular, the employees in SME in our case study areas rather often emphasized pragmatic (lack of finance, of knowledge about the right contact partner) and some psychological reasons (feeling of inferiority against university professors, different motivation), which only partly cover cognitive distance for a lack of cooperation with potential partners that would enable a combination of different knowledge bases. Hence, neither organisational barriers (local government's innovation policies have at least explicitly addressed them in recent years) nor cognitive distances alone are able to explain the described under-exploitation of combinatorial knowledge potentials in both case study areas. Thus, we structured the eight topics relating to barriers to combining different knowledge bases in terms of the geographical dimension, as well as whether the barrier have to be addressed on an individual or organizational level.

Figure 2: Level of barrier solutions



In the case of *financing*, it became clear that a mismatch between the existing state funding structure and the needs of SMEs exists. To reinforce knowledge exchange among and within the knowledge bases, minor subsidies especially for small enterprises would be helpful. For example, Bavaria offers innovation coupons for firms with fewer than 50 employees, craftsmen, entrepreneurs and freelancers who require €4,000 to €15,000 for innovation cooperation with external firms (Bayerische Gesellschaft für Innovation und Wissenstransfer, n.d.). This could also be fruitful in Lower Saxony, the federal state of the two case study regions. Thus, action to reduce financial barriers to combinatorial knowledge dynamics is necessary for national organizations such as the Ministry for Economic Affairs and Energy. However, the factors that hamper knowledge exchange are interrelated, bringing to the fore that policy instruments cannot primarily be monetary. Recent empirical research on knowledge bases found that a shift from technology-based policy to integrating other forms of knowledge, for example from the cultural and creative economy, are becoming increasingly important (Halkier et al., 2012). This shift is only partly visible in our findings. Almost all of the interviewees stated that there was an increasing interest in different knowledge, meaning analytical and synthetic knowledge. Only a few interviewees spontaneously integrated symbolic knowledge exchange into

their answers, indicating a gap between the research findings and practice. This political perseverance is in line with (Halkier et al., 2012), who stated that, traditionally, the integration of symbolic knowledge does not belong to the core activities of regional innovation policy.

Combining different types of knowledge was also hampered by finding the *right contact person*, which is in line with the argument of organisational proximity (Boschma, 2005). Both regions had established TTOs for analytical and synthetic knowledge exchange, which is an important milestone in forcing knowledge exchange. Nevertheless, they need professionalization to ensure financial continuity and the competence of the staff (Innovationszentrum Niedersachsen, 2018, S. 3–4). There is potential to handle this barrier at the local and federal state's levels. On the one hand, the focus of the universities and the regional demand should be more attuned, which is also important for countering skill shortages. On the other hand, the state should provide a research information system for the greater transparency of existing cooperation (Innovationszentrum Niedersachsen, 2018, S. 3–4). The latter could reduce the *length of time* expended in searching for the right contact person with an analytical knowledge base.

In the case of the barrier topics, *outcome of cooperation* and *publishing,* solutions could be addressed at the regional and state levels, touching individual and organizational dimensions. Containing a large variety of reasons, policy-makers have to support not only the stage of finding each other, but also negotiations on publishing and implementing the outputs of innovation cooperation.

In contrast, the topics *psychological barriers* and *interest in different knowledge* can be addressed at the local and individual levels. Local facilitators, such as the TTOs or innovation consultants, could elucidate the process of knowledge transfer between different actors, such as professors or creatives. Bearing in mind that most of the perceived barriers to get in touch with symbolic knowledge are based on prejudices, local policy-makers could overcome this bias through promoting such exchange. Also, firms' internal learning processes have to be open to other knowledge. Hence, if psychological barriers are understood as being a part of cognitive distance, these barriers seem to be easier to handle for innovation policy than protagonists of an evolutionary economic geography perspective would suggest (Boschma, 2005; Grillitsch et al., 2018). They could indirectly reduce this obstacle, for example, through workshops about different processes of learning and the promotion of openness for knowledge exchange and

creativity, regardless of hierarchy. Several SMEs stated that analytical or symbolic knowledge would be unimportant for their innovation processes. We interpreted this as a sign of them being aware of the innovation phase. Combinatorial knowledge dynamics could be fruitful during the ideas and distribution phases, but maybe not during implementation, which would profit more from cumulative knowledge exchange within one knowledge base (Strambach & Klement, 2012).

Professionalising combinatorial knowledge dynamics can be obtained through co-working spaces in both regions. The biggest co-working space in Lower Saxony is located in the Region of Hanover (with more than 1,000 members), supplemented by several smaller co-working spaces in the city. It is notable that, in Goettingen only one private co-working space is available, despite the considerable number of students and innovative firms there (Innovationszentrum Niedersachsen, 2018). It would also be helpful to support the maker scene in Goettingen, even outside the university, as recently done by the Region of Hanover. Makers have high technical competencies, developing potential for new ideas in sectors such as electronics, machinery and materials supply (Innovationszentrum Niedersachsen, 2018). Nevertheless, a stronger exchange of information between makers and firms could be implemented.

The Region of Hanover and the Goettingen district also support creatives through specialised networks (Schlote, 2012). In general, this offer differs in many aspects between both regions. While in the Region of Hanover the creative network is connected to local business promotion service, the network in Goettingen is based on voluntary work. This could be one reason for the fact that it is less known than its counterpart in Hanover. Also, several creatives do not use the support of the network, for example, the website. This can be explained by the age pattern of creatives in Goettingen district, which is above 40 years, the consequence being a lower attachment to digitalised offers. The major publishers in Goettingen district are not members of the network either.

We found different *perceptions of potential for combinatorial knowledge exchange* in the two regions. While the Region of Hanover reflected a balanced potential for learning from different knowledge bases, Goettingen district focused on combining analytical and synthetic knowledge. This is manifested in organisations such as the Measurement Valley or Innovation Campus SNIC (Innovationszentrum Niedersachsen, 2018). The latter in particular is an outstanding example of inter-institutional and interregional cooperation fostering the bilateral exchange of analytical and synthetic knowledge

(Innovationszentrum Niedersachsen, 2018). The SNIC office coordinates this exchange on a decentral way, and reaches a consensus beyond district borders. Focusing on the health economy, industry 4.0 and new martials/production processes, the SNIC brings together different, but related knowledge and learning activities. This is in line with the platform strategy suggested by Asheim et al. (2011). Thus, the SNIC activities can be considered as a role model for other regions with similar environments. Despite the fact that Goettingen district is averagely specialised in the symbolic knowledge base, we observed only minor political interest in this type of knowledge. According to the self-promotion of both regions on their websites, the Region of Hannover has its economic strengths in 12 leading sectors, including the inter alia automotive industries, creative economy and science and research (Region Hannover, 2017), while Goettingen city highlights measuring technology, logistics, the health economy and publishing (Stadt Göttingen, 2020b). The latter only lists all the publishers in Goettingen. In fact, we found one organisation that brought the analytical knowledge of the university together with the symbolic knowledge of publishing that was only a small part of the symbolic knowledge base Goettingen district provides (Literarisches Zentrum Göttingen, n.d.). However, we could not find any political intention of bringing symbolic knowledge together with the analytical and synthetic knowledge bases. One interviewee with a symbolic knowledge base illustrated this:

> There is so much potential because we have many people doing suspenseful work. I get to know them accidentally through personal contacts or my job activities. I think that Goettingen perceives itself as being less worthy. This is one of the most terrible experiences. (C9)

What has been left out so far are the knowledge dynamics between firms relying on the (informal) DUI-mode of innovation and a symbolic knowledge base. Indeed, Florida's (2003) creative class approach has occasionally been transferred into political practice. We have documented that this only ends up in promoting specific core industries separately, but not the knowledge exchange between those relying on different knowledge bases.

We argue that regional innovation policy has to consider this complexity and diversity in innovation processes, and therefore communication and participation strategies should be rethought (Martin et al., 2011). This includes bringing together different knowledge

bases, acknowledging different modes of innovation (Jensen et al., 2007), instead of promoting only particular sectors and regions (Asheim et al., 2011). Networks that are technology- or application-oriented tend to be more fruitful for learning processes than exclusively sector-specific networks (Innovationszentrum Niedersachsen, 2018).

Actually, we also detected some preliminary events to overcome this limitation. In the Region of Hanover, the creative network KreHtiv, in cooperation with the entrepreneurship centre NEXTER at the University of Applied Science and Arts, Hanover, and other partners have organised workshops handling future themes such as mobility, health, digitalisation and integration yearly since 2012 (kre|H|tiv Netzwerk Hannover e.V., 2017). In these 'HannoLaps', creatives, participants of private enterprises or institutions, as well as students from the Design and Media master's programme of the Applied Science University, Hanover, are involved in exchanging knowledge from different knowledge bases, creating innovative solutions. This exchange of insights using combinatorial knowledge could be a useful option for organisational, marketing and social innovation. We found few, but related activities in Goettingen, 'integrating creatives in city planning activities for some quarters' (C9). Thus, we conclude that combinatorial knowledge dynamics are not only successful for firms, but also for the public sector. Local innovation policy-makers must understand that organisations and individuals can be incentivised through these inter-sectoral events.

2.5 Conclusions

In this paper, we discussed how and why combinatorial knowledge dynamics are hampered in practice and how innovation policy may help. This is important in order to guide policy organizations to transfer theoretical insights into a contemporary place-based policy approach. As described in Section 2.2, knowledge bases are ideal typical constructs for integrating different, individual micro-level learning activities. However, firms and macro-level systems, such as innovation systems or regions, learn and innovate through combinatorial knowledge dynamics (Manniche, 2012). Using the knowledge base approach as an analytical tool, we have provided an overview of the perceived practical barriers to knowledge combination. Our in-depth investigation in two sample regions has not only highlighted the local factors that hamper combinatorial knowledge dynamics, but also the barriers that can only be solved at the federal state or national

levels. Barriers in terms of too little cognitive and organizational proximity as postulated in parts of the literature, were less important in practice. Clarification about potential partners as well as initiation of first contacts through trustworthy local innovation consultancies may foster combinatorial knowledge exchange. From a policy perspective, this emphasises the need to be aware of different knowledge types, and hence different modes of learning (Jensen et al., 2007). As a consequence, the range of innovation policy instruments must include science and engineering, as well as cultural perspectives, to support the creation and use of knowledge in an economically relevant manner (Manniche, 2012, S. 1836).

Of course, this exploratory study had a few limitations, which should prompt further research. First, while some of the barriers in the studied regions seemed to be quite similar (such as financial support or the importance of organisations in finding the most appropriate cooperation partner), other topics differ in the details. Acknowledging that the devil is in the detail, we advise regional policy-makers not to copy successful strategies, such as best practices, into other regions before analysing the existing regional framework (see Tödtling & Trippl, 2005) because, as with all case studies, we are unable to transfer our qualitative empirical results to other regions. Second, following an evolutionary approach, a region's specialisation may vary over time, and barriers to combinatorial knowledge can be affected by changes in specialisation. Shifting from one knowledge base to another could involve different strategies of combination (Boschma, 2018). Third, there is still no ideal solution for measuring the outputs of combinatorial knowledge dynamics. In order to reproduce the impact of knowledge exchange organisations (such as the SNIC in Goettingen district), we need better indicators containing informal DUI-mode learning processes and innovation outputs beyond patent data and new products.

3 Combinatorial Innovation Modes in SMEs: Mechanisms integrating STI- processes into DUI-mode learning and the role of regional innovation policy

Author: Harm Alhusen and Tatjana Bennat

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Abstract

Innovation processes comprise interactive learning mechanisms by combining different knowledge sources. Using a set of 80 exploratory interviews with small and medium-sized enterprises (SMEs) and regional innovation consultants, this paper analyzes the mechanisms through which firms combine an STI (science-technology -innovation) and DUI (learning-by-doing, -using and -interacting) mode of innovation. We show that the innovation mode concept ought to be applied as a continuum of combinations. Thus, SMEs integrate STI-based knowledge into DUI-routines through mechanisms with varying levels of complexity. The described mechanisms differ with respect to their effects on innovativeness, the required absorptive capacities, and costs incurred. Depending on the level of integration, cognitive, organizational and financial barriers impede a combination of innovation modes. At this point, regional innovation consultants can affect a successful combination. We derive implications for innovation policy regarding absorptive capacities in SMEs, showing that policy support extends beyond financial services.

Keywords: innovation modes, DUI, Regional Innovation System, R&D cooperation, knowledge bases, regional innovation policy

3.1 Introduction

In comparison with larger corporations, SMEs often innovate with lower or no explicit expenditures on R&D or R&D departments (Brink et al., 2018; Rammer et al., 2009). Moreover, innovation is a cumulative and interactive learning process, requiring more than firm-internal knowledge dynamics and therefore a combination of different resources and the involvement of a variety of actors (Asheim et al., 2016; Grillitsch & Rekers, 2016). Research shows that firms combining different ways of knowledge-creation and learning processes are more likely to introduce product and process innovations (Thomä & Zimmermann, 2019b). A recent contribution to different types of knowledge-creation was made by Jensen et al. (2007), who introduced the STI (science-technology-innovation) and DUI (doing-using-interacting) mode of innovation to explain a firm's innovativeness regarding different ways of using knowledge from internal and external sources.

Building upon Jensen et al. (2007), substantial research has been conducted on user-driven DUI and science-driven STI modes of innovation (see: Apanasovich, 2016; Parrilli, Fitjar & Rodriguez-Pose, 2016 for reviews). Successive contributions have shown that a combination of both innovation modes leads to higher innovation outputs (Parrilli & Heras, 2016; Thomä & Zimmermann, 2019b). However, little is known about firms internal changes in learning routines and the difficulties of combining innovation modes related to the combination of innovation modes. The underlying knowledge base as well as the way in which knowledge is created and sustained differs with respect to different innovation modes (Asheim et al., 2007; Aslesen & Pettersen, 2017). Therefore, a combination of innovation modes can be difficult for SMEs, as they often have little or no science-based learning routines (Bennat & Sternberg, 2020; Nunes & Lopes, 2015). This results in lower absorptive capacity (Cohen & Levinthal, 1990) to integrate STI-routines into a firm's DUI innovation mode. The aim of this paper is to analyse mechanisms that SMEs use to combine innovation modes at a micro-level and how this process can be supported by regional innovation policy. Using a set of 80 exploratory interviews with SMEs and regional innovation consultants, this paper contributes to a better understanding of how SMEs combine the DUI and STI mode of innovation. We explain how SMEs search for and integrate knowledge from a STI innovation mode into their innovation process using codified knowledge, employee knowledge and R&D collaborations. These insights are combined with findings on regional innovation policy

activities and its role in combining innovation modes. Hence, we investigate the role of regional innovation consultancies in affecting firms' combinatorial innovation modes and demands for regional policy changes. The process of cooperation establishment among different actors, knowledge creation and its effective integration in firms' innovation processes are explained.

The next section provides a critical discussion of previous contributions and introduces our conceptual framework. In section 3.3, we describe our methodology and our qualitative data collection, while in section 3.4 the results of our analysis are presented. The fifth section discusses the findings and presents policy implications. Finally, a conclusion is provided in section 3.6.

3.2 Theoretical Concepts and Literature Review

3.2.1 Modes of innovation

DUI mode innovations are based on the application of mostly tacit and synthetic knowledge with a focus on know-how and know-who (Jensen et al., 2007; Johnson, Lorenz & Lundvall, 2002). Learning is more informal and conducted through doing, using and interacting as a holistic concept of innovating. Jensen et al. explain that learning-by-doing and -using both "involve interaction between people and departments" (2007, S. 684). Nevertheless, most studies aim to measure DUI innovativeness based on a firm's internal or (more commonly) external interactions (Apanasovich, 2016a), using indicators of either learning-by-doing, -using and -interacting as representative for the DUI mode of innovation (see for overview Alhusen et al., 2019; González-Pernía, Parrilli & Peña-Legazkue, 2015; Parrilli & Heras, 2016). Nevertheless, the learning mechanisms of DUI differ in many aspects (e.g., actors involved, firm-internal and -external processes, and usefulness at different stages of innovation processes). Thus, learning-by-doing results from work experience and increasing skills in production (Arrow, 1962; Thompson, 2010), using as feedback from users and their involvement in improving products and services (Rosenberg, 1982), and interacting as a product of interaction between firms, suppliers and competitors as well as other actors (Jensen et al., 2007; Lundvall, 1985). Innovation outputs are often incremental productivity gains, such as cost reductions or quality improvements, but they can also be new customer-specific products (Hippel, 2005). The DUI mode is fueled by qualified and experienced workers as well as

organizational structures that foster employee involvement in innovation processes (Apanasovich et al., 2016; Apanasovich et al., 2017; Jensen et al., 2007; Nunes & Lopes, 2015; Parrilli & Heras, 2016).

By contrast, STI mode innovations rely on the production and exploitation of scientific and technical knowledge, usually codified and based on know-what and know-why. This analytical knowledge is usually developed at universities or by R&D departments, often in cooperation with other research institutions (Johnson et al., 2002). Searching for new knowledge or scientific principles, formal R&D is a driver of new products or process innovations (Jensen et al., 2007). Scientifically-trained workers and R&D investments hold vital importance for generating innovation in the STI mode (Isaksen & Trippl, 2017; Johnson, 2010). Without such an internal R&D department, the procession and accumulation of firm external scientific knowledge is less likely to occur (Amara et al., 2008; Cohen and Levinthal, 1989). The STI mode is generally associated with the production of radical innovations (Nunes & Lopes, 2015).

3.2.2 Combination of innovation modes

Jensen et al. (2007) results already indicated that a combination of innovation modes results in higher innovative performance and many studies find that a combination of innovation modes has a positive impact on innovation outcomes (Apanasovich et al., 2016; Apanasovich et al., 2017; Chen et al., 2011; Fitjar & Rodríguez-Pose, 2013; Fu, Revilla Diez & Schiller, 2013; González-Pernía et al., 2015; Jensen et al., 2007; Nunes & Lopes, 2015; Parrilli & Heras, 2016; Thomä, 2017). Also, the literature on innovation collaboration mentions that various partners may provide different types of knowledge, enhancing firms' innovation potential (Bennat & Sternberg, 2020; Cooke, 2012; Strambach & Klement, 2012). Thus, the literature on innovation modes describes a combination of different interaction-types either as complements or substitutes (Haus-Reve et al., 2019). Combining scientific and supply-chain synthetic knowledge, which are important elements of the STI und DUI mode, thus fosters firm-level innovativeness: for example, Fu et al.'s (2013) 'intensive interactive learning group' relies on DUI and STI drivers and outperforms other learning groups regarding product innovation. Apanasovich et al. (2016) point in the same direction and shows that firms with higher levels of DUI and STI possess a higher probability of innovating, arguing that a combination is the most effective innovation mode. Isaksen and Karlsen (2012a, 2012b) introduced the combined and complex (CCI) mode for the Norwegian automotive

industry (Isaksen & Karlsen, 2012a) and an oil and gas cluster (Isaksen & Karlsen, 2012b). The CCI mode is described as a combination of both DUI and STI, similar to the DUI (technological) mode by Aslesen et al. (2012). According to their definition of combination, CCI-firms moderately use internal R&D, conduct technological projects and patent activity, albeit with a focus on prototype development and innovations relying on both expert and experience-based knowledge. The CCI mode therefore relies on both analytical and synthetical knowledge, combined with external knowledge from universities as well as customers.

Thomä and Zimmermann (2019b) show that a culture that emphasizes learning from failure and non-material incentives for employees is used as a substitute for internal R&D and Human Resources Management (HRM) practices. A recent study by Haus-Reve et al. (2019) point into the same direction finding evidence that collaboration with scientific and supply-chain partners are substitutes. Their analysis of Norwegian firms revealed a negative interaction between scientific and supply-chain collaboration for product innovation, implying that they are substitutes rather than complements. In the first case, firms would move on a continuum between two ideal types and choose what combination of DUI and STI drivers best fits their needs. In the second case, firms' innovativeness increases with an increase in either DUI or STI drivers. These findings challenge the prevalent opinion asserting the benefits of combining different innovation modes. Nevertheless, Haus-Reve et al. (2019) analysis only includes collaborations with actors having different knowledge bases, influencing product innovation. It remains unclear whether a combination of DUI and STI learning mechanisms (which are more than collaborations) will also point in the same direction and whether this implies that "doing more of all" is a successful strategy for innovation in SMEs (Haus-Reve et al., 2019).

Further contemporary studies explore the use and combination of innovation mode drivers by using case studies in specific industries, namely the food industry (Trippl, 2011; Trott & Simms, 2017), oil supplier and biotechnology industry in Norway (Aslesen & Pettersen, 2017; Isaksen & Karlsen, 2010) and the automotive supplier industry (Holtskog, 2017; Isaksen & Karlsen, 2012a). They describe ideal-typical components of innovation modes and categorize industries or clusters as belonging to either the DUI or STI mode. However, the very same studies have questioned this assumption. For example, in one case firms from the food sector have been categorized as relying on the DUI mode, having no internal R&D capacities and not using STI drivers of innovation

(Trott & Simms, 2017). However, Trippl (2011) identifies firms in the Vienna food sector operating mainly in the DUI mode, but also use knowledge from scientific partners like universities and research centers.

It becomes clear that existing studies focus on various indicators of innovation modes, e.g. knowledge types or sources, and vary strongly in their definition and thus interpretation of a combinatorial innovation mode. In sum, multiple ideas exist regarding what constitutes a combinatorial innovation mode. Studies are missing that explore mechanisms of how innovation modes are combined in practice. Therefore, the first research questions this paper intends to answer is:

RQ1: How do SMEs successfully combine a STI and DUI mode of innovation?

However, as the original idea of innovation mode is a holistic view of mechanisms (Jensen et al., 2007), we expect a strong interdependence between the micro-processes of combing both modes. This expectation is also based on previous studies which analyzed SMEs, indicating that ideal types of innovation modes hardly exist in practice: this was already described by Isaksen and Karlsen (2010), which they dubbed as hybrid forms of innovation modes. This insight is further supplemented by entrepreneurial studies exploring how their use of innovation modes is related to their stage in the innovation process (Aslesen and Pettersen, 2017) and a case study by Holtskog (2017) on the intertwined use of DUI and STI and the problem of timing as a critical analytical dimension for determining a company's innovation mode. Thus, we argue that describing a company as innovating in either the DUI or STI mode based on a sectoral classification can be problematic as there are often even intra-sectoral differences of innovative behavior. Some firms across different sectors generally using the DUI mode can add STI-elements when it fits their strategy (Trippl, 2011; Isaksen and Karlsen, 2012b). Therefore, the combination of the DUI and STI mode is not industry-specific and effectively often occurs similarly in related, but different industries. This leads to the first proposition:

Proposition I: The innovation mode of a firm must be deducted by the mechanisms it is using, as there exists no universal innovation mode for sectors.

However, adding STI elements to a firm's innovation process not only depends on its strategy; rather, its successful integration is hampered by several barriers (Bennat & Sternberg, 2020; Thomä, 2017).

3.2.3 Expected barriers and the role of regional facilitators

The importance of combining innovation modes begs the question why firms do not combine them more often. SMEs usually make small investments when incrementally changing current products but are wary when it comes to high investments regarding new developments. New developments are associated with higher returns but also pose tremendous risks. Having no R&D departments saves SME resources (Rammer et al., 2009). At the same time, it reduces a firm's absorptive capacity (Cohen and Levinthal, 1990) for scientific knowledge, when no academic recruitment takes place (Herstad, Sandven & Ebersberger, 2015). This conflict between work routines, existing knowledge and new external knowledge can be an obstacle to combining both innovation modes (Herstad et al., 2015). Marginal in-house R&D and less absorptive capacity make it difficult to switch from a traditional DUI mode to an STI mode of innovation (Isaksen & Nilsson, 2013).

Bennat und Sternberg (2019) explicate practical barriers to combinatorial knowledge dynamics. For example, organizational barriers and cognitive distance between SMEs and universities limit the ability and willingness to combine different knowledge types, which also could have consequences for combining innovation modes. This leads to a second proposition:

Proposition II: The combination of innovation modes is hampered by several barriers.

Innovation results from complex, interactive and cumulative learning processes (Asheim et al., 2016), involving knowledge dynamics between a variety of actors, also driven by unique regional framework conditions (Boschma, 2005). Governments are aware of this fact and have established local services especially for SMEs to increase innovativeness by overcoming their limited "internal specialized 'information processing' capacity" (Toner, 2011, p. 62). Given the increasing importance of knowledge and technology transfer for innovation policy (BMBF, 2018), we assume that regional innovation consultancy plays a crucial role in connecting DUI-SMEs with STI-partners, thus upgrading their capacities to integrate STI-knowledge into their innovation processes. While competitive advantages are constantly under pressure for change, regional policy-makers support interactive learning, and hence regional cooperation (Martin et al., 2011, S. 552). These regional framework conditions continue to be shaped by policy-makers to create competitive advantages (Martin et al., 2011) ending in a third proposition:

Proposition III: Regional innovation policy is affecting the combination of innovation modes in firms.

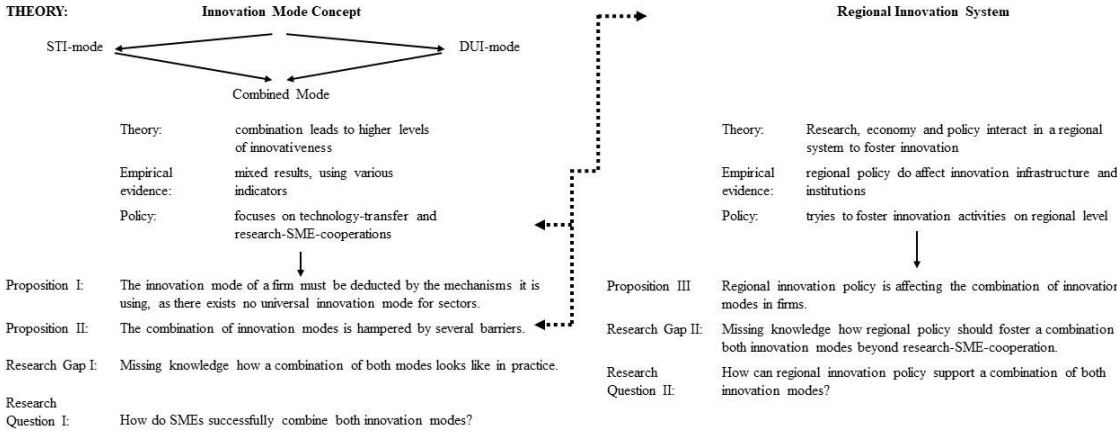
However, the traditional understanding of innovation processes leads to an STI mode of policy framing (Cooke, 2014). However, previous studies have shown that firms innovating in different modes may need different types of support. For DUI firms, a broader understanding of a regional innovation system (RIS) (Cooke, 2014) including 'all the actors and activities that affect learning, knowledge creation and innovation in a region' (Isaksen & Karlsen, 2013) is more appropriate. Thus, universities are not only 'innovation factories' but also an important source of skilled labor. A broader defined RIS also encompasses a specialized labor market, applied research institutes, non-R&D-based business services and an innovation culture of sharing knowledge (Isaksen & Karlsen, 2013). Depending on the organizational thickness and diversification of a specific RIS and a firm's size, its knowledge base, innovation mode, and the geographical source of new knowledge varies (Aslesen & Pettersen, 2017; Isaksen & Trippl, 2017). Interacting at regional level helps SMEs to save human and financial resources. Following Coletti (2010) or Cooke (2014), it becomes more important to designate central facilitators who direct knowledge flows into the right channels. While innovation processes involve an increasing number of actors, new knowledge needs to be translated and transferred (Aslesen & Pettersen, 2017). As no unified picture of a combinatorial innovation mode exist across studies, little is known about the mechanisms of combining innovation modes in SMEs. With the political goal of fostering innovation, an understanding of internal mechanisms is especially important. This offers practical insights to promote of a better combination of innovation modes through regional innovation policy (Apanasovich et al., 2017; Aslesen & Pettersen, 2017; Isaksen & Karlsen, 2012a).

In sum, the RIS literature highlights the role of regional policy in innovation processes, calling for tailor-made support strategies, that recognizes the existing regional innovation structure (Martin et al., 2011) and its historical contingency (Asheim et al., 2011). However, less is known how this support should look like in practice going beyond the boundaries of the trend of technology transfer activities and the continuous improvement of R&D infrastructure, which we identified as a second research gap. Therefore, the second research question this paper intends to answer is:

RQ2: How can regional innovation policy support a combination of both modes?

Hence, this paper contributes to existing DUI literature given its strong connection with ideas of RIS and firm-internal management processes. The following graphic summarizes the literature review and illustrates the theoretical concept of this paper.

Figure 3: Theoretical framework of the analysis



3.3 Method and Data

We choose an exploratory qualitative approach, which is best suited for research that addresses "how" questions that allows for a broader exploration of research questions and inductive theory building (Eisenhardt, 1989; Eisenhardt & Graebner, 2007). We used qualitative interviews as an insightful tool for analyzing the mechanisms behind innovation mode combinations.

3.3.1 Sampling

Due to the vague theoretical concept of innovation modes, little is known about core processes manifesting each innovation mode. This had consequences for sampling strategy. Representativeness of findings is not a purpose of qualitative research. It rather looks for cases that are helpful to constructing a corpus of empirical examples for studying the phenomenon of interest. The sample should capture the variation and variety in the phenomenon under study as far as possible (Flick, 2018). Therefore, a more "loose design" (Miles & Huberman, 1994) is appropriate when theoretical concepts are under-developed (like the innovation mode concept), with offers openness and flexibility as needed (Flick, 2018). The goal of sampling was to cover multiple possible DUI micro-

processes. Therefore, we followed a purposive sampling strategy seeking cases that assert themselves as innovative.

Thus, in a first step we identified SMEs that presented themselves as innovative through a) publicly-available information, such as participation in innovation awards, b) website analysis, c) snowball sampling since interference between the cases could be negated (Schreier, 2007), or d) suggestions of regional innovation consultancies. After theoretical saturation (Glaser and Strauss, 1967), we extracted the processes that were described as important for innovation in each case (SME). After that analysis, we examined how these processes can be ascribed to the theoretical categories of each innovation mode. Thus, all processes connected with formal R&D departments, research cooperation or scientific knowledge were allocated as STI processes. Processes relying on learning-by-doing, -using or -interacting were summarized as DUI mode. Some important factors for innovation in SMEs could not be covered by the theoretical concept of innovation mode, which we summarized under "further important factors" (for example, the influence of a firm's innovation culture). This allows us to categorize every SMEs effort according to their innovation activities, belonging to either the STI or DUI mode.

As the research interest was to find patterns between the interviewed firms that are not industry-specific as well as to capture the variety of micro-processes, we included SMEs from a broad range of sectors (see Table 4). We do not imply that all processes that we allocated to the theoretical concept of DUI or STI have to exist in all SMEs regardless of their industry or organization; rather, we were interested in collecting all shades of mechanisms that allow for a combination of learning-by-STI and -DUI.

Table 4: Overview of interviewed industries

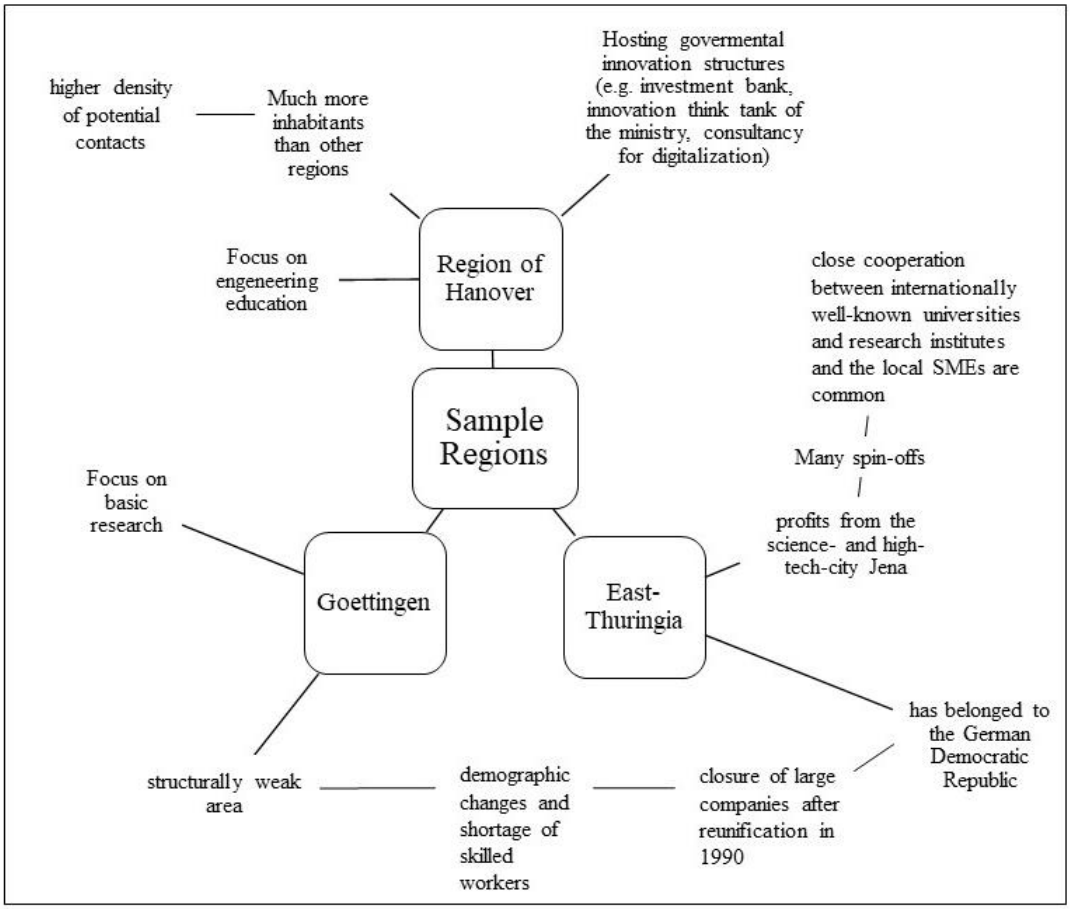
Industry[5]		No. of SMEs
Agriculture, forestry and fishing		1
Mining and quarrying		1
Manufacturing	Manufacture of food products/ beverages	3
	Manufacture of computer, electronic and optical products	14
	Manufacture of fabricated metal products, except machinery and equipment	6
	Manufacture of chemicals and chemical products	1
	Manufacture of machinery and equipment n.e.c.	3
	Other manufacturing, and repair and installation of machinery	1
Construction		2
Wholesale and retail trade; repair of motor vehicles and motorcycles		4
Information and communication		6
Professional, scientific and technical activities		4
Other service activities		1
Human health and social work activities		1
Administrative and support service activities		1
∑		49

Further, we extended the cases with interviews of (private and public) regional innovation consultancies, whose principle tasks are to establish knowledge networks and support regional SMEs. We use this second group to compare firm insider and outsider views. We analyze the interviews of the SMEs to explore an insider view of the practice of combinatorial innovation modes. As regional innovation consultancies could overestimate their own importance, we contrast the explanations of the SMEs with answers of the regional innovation consultancies. In addition, regional consultancies possess knowledge about many different SMEs, which helps us to understand the variety of mechansims used and barriers with which SMEs are confronted. The interviews with consultancies are not used to answer a question if they are important for combining innovation modes at all. This was rather deducted from the interviews with SMEs.

[5] Industry classification referring to the NACE Rev. 2 statistical classification of economic activities in the European Community.

We focused on the three German planning regions ('Raumordnungsregionen [6] ') Goettingen, Hanover and East-Thuringia to cover three different RISs. All regions include metropolitan areas, implying 'organizationally thick' RIS, although their economic structures are based on different specializations (Isaksen & Trippl, 2017, S. 125) and are characterized by a relatively high number of SMEs. Universities and research centers are available in each of these regions, allowing local cooperation with STI partners. For more details, see the following figure:

Figure 4: The three sample regions in detail



[6] Functional division of analytical grids in Germany based on districts and commuting flows.

3.3.2 Interview process

Between February and October 2018, we conducted interviews with 49 firm representatives and 31 regional innovation consultants (see List of Interviews)[7]. After an initial problem analysis using previous theoretical and empirical contributions, we summarized core aspects of our research into two interview guidelines (see appendix I) that comprised open questions (Flick, 2017): one for SMEs and one for consultants. The interviewees were asked to explain in detail how innovation with and without R&D activities takes place. Anonymity was ensured to all interviewees. The interviews were recorded and transcribed afterwards. Using these transcriptions, we conducted a content analysis as suggested by Mayring (2010), incrementally reducing the content of the interviews to statements that was relevant to our research questions. We used deductive categories for information that was related to our guideline questions and inductive categories for information that was new to us. We further condensed the codings into summaries and inductively developed more nuanced subcategories. In turn, these are used for the analysis, upon which the results are built. We cite abstractions or statements made by SMEs with a 'F' and from regional innovation consultancies with a 'C', followed by the number of the interview in accordance with our internal data base.

3.4 Results

We first identified all processes that are relevant for innovation in the sampled SMEs. However, practice was more complex than theory suggests. Despite the sample of 49 SMEs from different sectors, we could not describe a single firm that innovates solely through a DUI or STI mode. For example, even the mortician integrated analytical codified knowledge via trade magazines or scientific theory from a previous study to identify market potential for his innovation (F17). We also found DUI mechanisms in firms that had a R&D department. For example, one university spin-off with a R&D department integrated customer into innovation projects and highlighted the importance of learning-by-doing of its employees (F32).

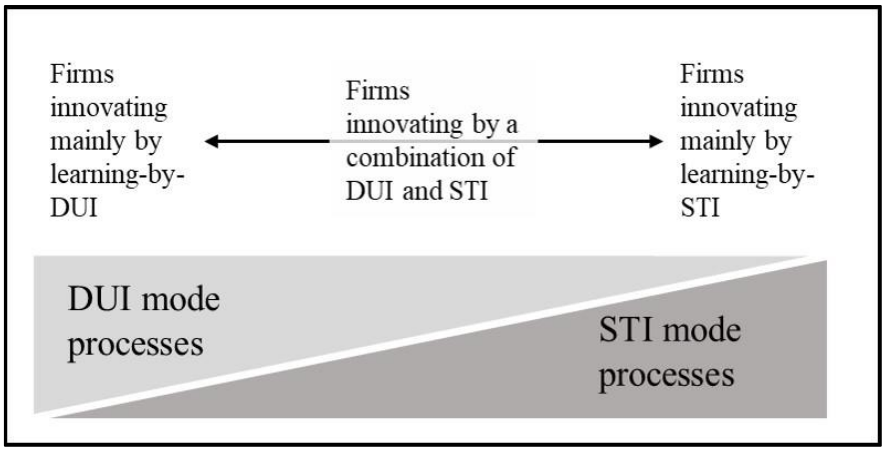
Thus, we argue that in accordance with previous qualitative studies, ideal types of innovation modes hardly exist in practice. However, this does not mean that every innovative firm belongs to the group of combiners; rather, we argue that the innovation

[7] Interview Sample: Goettingen: 10 RICs/ 18 SMEs; Hanover: 12 RICs/ 15 SMEs; East- Thuringia: 9 RICs/ 16 SMEs

mode concept has to be understand as a continuum of processes with mainly three types of firms (Figure 5):

1) Firms mainly innovating by learning-by-DUI
2) Firms combining DUI and STI and
3) Firms mainly innovating by learning-by-STI

Figure 5: Continuum of processes referred to DUI and STI mode of innovation



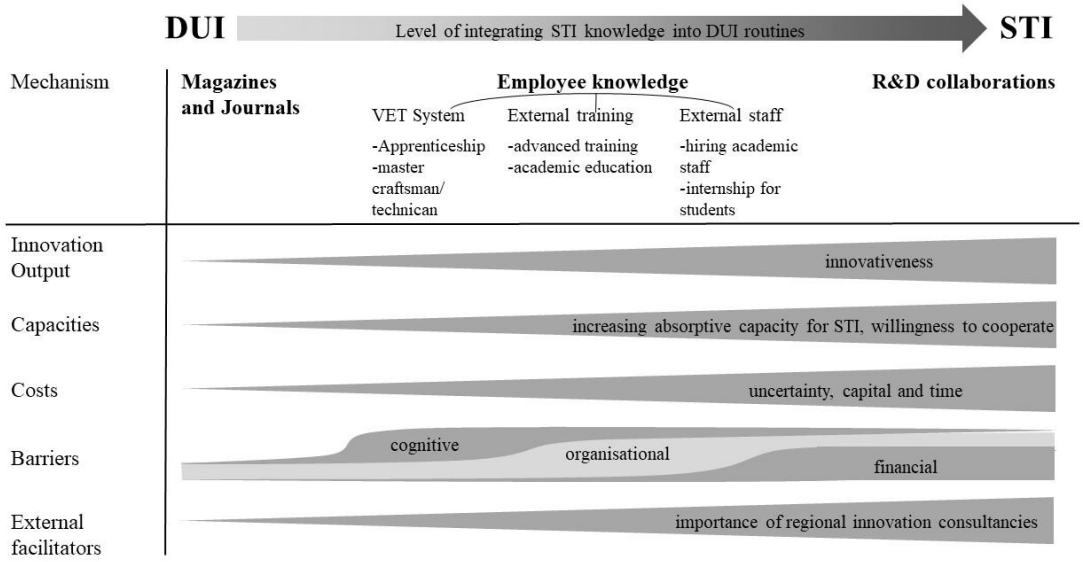
The interviews highlight the notion that proxies like industry classification are not sufficient to categorize an SME as a DUI or STI innovator, thus emphasising proposition I. For example, two firms that produce printed circuit boards with both more than 90 employees strongly differ in the level of how they use STI-based knowledge. The first interviewee pronounced a) the importance of an academic workforce, b) the fact that his firm engages in research projects with universities and research institutes and c) learning mostly takes place through their R&D department (F31). However, the second only integrates academics to seek scientific knowledge and did not use further mechanisms of learning by STI (F39). Thus, we place the first one much more right of the continuum of DUI and STI processes than the second one, although they belong to the same industry. Another example is university spin-offs: one might think that spin-offs mostly learn by STI processes, as they already have strong ties to a scientific institution. However, we also identified university spin-offs whose product improvements are mostly based on DUI processes (F46). Moreover, the sole differentiation into different innovation modes based

on the presence or absence of a R&D department proved insufficient for categorizing SMEs. For example, a firm in the engineer-to-order business had a R&D department, but hardly learned through scientific research. In their R&D department, innovation is mostly based on a DUI mode, focusing on product development and not basic research. The same firm also engaged in university collaboration for organizational innovation. However, the interviewee evaluated this as a waste of time and did not learned from that collaboration. Thus, one might put 'university collaboration' on his list of mechanisms used, although it was not helpful to him to learn. It illustrates that ranking a firm as innovating in a DUI or STI mode can only be sufficient by focusing on the mechanisms used and the firm-internal evaluation of them. We therefore decided case by case how to place SMEs on that continuum, based on their use of our analyzed mechanisms.

Second to answer RQ 1, we explain all mechanisms through which the sampled firms combine DUI and STI and how these three types of innovators differ in their mechanisms used to combine DUI and STI. We deduce mechanisms of combinatorial innovation modes, based on the different sources of STI knowledge described by the interviewees. The mechanisms are: i) use of codified knowledge; ii) employee training and knowledge, and iii) R&D collaborations. The following chapter rates the mechanisms according to their complexity described by the interviewees. We start with the easiest integration of STI in firm processes and end with the most difficult. All analyzed mechanisms entail five dimensions: a) innovative results, b) capacities required, c) costs involved, d) barriers, and e) the role of regional facilitators.

We detect an underlying structure of cognitive, organizational and financial barriers to combined innovation modes which meets proposition II. These are related to the continuum of combinatorial innovation modes but differ in intensity, depending on the mechanism analyzed. These perceived barriers raise the importance of available external advice, highlighting proposition III. Figure 6 illustrates the continuum of combinatorial knowledge mechanisms and the extent to which the discovered barriers are relevant at different levels of STI knowledge integration. A detailed description of the mechanisms, their dimensions and how regional innovation consultancy affects them is provided in the following.

Figure 6: Continuum of combinatorial innovation mode mechanisms



3.4.1 Using codified knowledge

Trade magazines are a common source of codified information about new developments. We classified 'trade magazines' as the mechanism constituting the lowest level of analytical knowledge integration. They represent the most accessible and cheapest form of technological knowledge allowing firms to capture ideas on new technologies or developments.

One reason for the use of trade magazines is that firms without a R&D department do not possess absorptive capacities and usually rely on experience-based knowledge (F17, F21, F25, F29, F37). Thus, the term '*trade magazines'* excludes academic journals. Trade magazines offer a general overview of new technological developments and therefore codified technological knowledge. Accordingly, they are more compatible with a user-driven approach to innovation.

Our sample firms possess the appropriate skills to apply knowledge from trade magazines to their firm-specific context. A search for new developments, using magazines alone, is neither sufficient nor does it happen systematically: One firm mostly innovating through a DUI mode explained: "Some people attain their technician degree while working part-time, but the real novelties, as I said, we see eventually at trade fairs or in trade magazines. […] something like that, searching systematically, we do not do" (F31). They are

motivated by a quick overview of new developments screening competitors and customers for the necessity and usefulness of adapting to novelties. The combination of trade magazines with other sources about market developments makes sense as both rely on learning-by-DUI and therefore follow a user-centric approach.

Although, using trade magazines as a source of STI knowledge might be simple, we found evidence that firms mostly relying on STI processes also used this mechanism. Hence, this mechanism should not be underestimated by politicians. However, we found differences in the sample: firms that at least partly relied on internal R&D mentioned *scientific journals* as important, as they supplied them with knowledge about current scientific research (F23). These firms used journals as a source of scientific knowledge and occasionally even published in journals. The motivation behind this firm behavior is to stay in contact with researchers, who were also customers, and improve their reputation within the scientific community (F7, F12, F23). Thus, scientific journals are often used by firms that already have STI-based knowledge, whereas trade magazines comprise rather applied analytical knowledge, making it also accessible for DUI-firms.

The innovativeness that results from this mechanism is low, as applicable ideas and knowledge often requires more than reading. The use of trade magazines requires less firm-internal, scientific capacities to acquire codified knowledge. The costs involved are relatively low as reading professional journals or trade magazines is not related to high investments or long-term commitments. Although important, codified knowledge in the form of trade magazines has limitations. Firms rely on their firm-internal knowledge when using them to combine a DUI and STI mode. However, a firm's knowledge base and absorptive capacities predetermine the types of codified knowledge that the former can effectively use for innovations.

Hence, we argue that this mechanism is only slightly impeded by cognitive, organizational or financial barriers. This is in line with the role of regional innovation consultancies: only few activities of regional innovation consultancies affect firms' combinatorial innovation mode regarding this mechanism. This might be because this mechanism is not associated with any 'real' interaction of different actors. SMEs that only used this method of STI integration explained that regional innovation consultancies are less important for their innovation activities (F19, F24, F34).

3.4.2 Employee knowledge

The next mechanism on the continuum of combinatorial innovation modes touches different aspects of *employee knowledge*. Employees are generally perceived to be a firm's most important asset and an important driver of innovations (F33). Firms that want to incorporate analytical knowledge rely on multiple mechanisms such as apprenticeship training, further training of employees, hiring university students and offering internships.

Learning-by-training through *vocational education and training (VET)* was mentioned by firms relying mainly on a DUI mode or a combination of STI and DUI processes. Apprentices in their early years were not mentioned as a major source of innovations in our interviews. However, VET training comprises analytical and synthetical knowledge and apprentices transfer this know-how into the firm, sustaining their firm-internal routines and capacities (F28). Regarding costs, SMEs prefer to hire employees for VET from their region who intend to stay within the region (F16). This allows SMEs to keep well-educated employees at the firm and prevent a drain of know-how after having invested in the education of apprentices.

All types of SMEs from our sample used *external training* as another way to source new scientific and technological knowledge (F6, F7, F24) and is widely used by German SMEs as indicated by official statistics (Statistisches Bundesamt, 2019). Employees ask for workshops tailored to their needs to increase the boundaries of their analytical knowledge (F7, F24, F29, F30, F31). Further training serves to increase a firm's capacity and motivate employees. Regarding innovativeness, employees learn how to operate new or current machines more effectively and learn about new developments in quality management or customer interaction (F29, F30). Furthermore, some employees suggest improvements to current products or processes based on insights from workshops (F7). A common practice is to send employees who are familiar with routines to external workshops to facilitate learning-by-training. These opportunities guarantee that external knowledge from workshops is successfully absorbed. The costs include workshop fees as well as payment for absent employees. However, the outcome in terms of new skills and knowledge makes it a positive investment (F24, F28, F43).

Another way to integrate STI mode was to recruit *external staff*. A popular way of integrating external staff with an analytical knowledge background was to hire students for part-time jobs or offer internships. Surprisingly, some firms relying mainly on DUI processes also used this mechanism (F47). However, our interviews indicate that they do

not recognize this as a potential to learn scientific knowledge. Firms combining DUI and STI were aware of this knowledge source. Indeed, all firms located on the STI side of the continuum integrated students as a source of scientific knowledge.

Employing students is one way to develop a firm's knowledge base used in a STI mode by adding new knowledge. Especially ICT students are capable of quickly introducing process innovations (F42). We infer that SMEs apply ICT practices only to a certain extent and employing ICT students allows SMEs to reap the profits of low-hanging fruits regarding process innovations through ICT introduction. Students with other backgrounds would nonetheless play a crucial role after some time. This is explained by a lack of practical knowledge. Students need to become acquainted with a firm's routines to apply analytical knowledge from a university to a practical context. As one CEO of an SME combing DUI and STI processes states: "At a certain point we lack the knowledge. These young, well-educated students from a technical college or university is what we will need in the future"(F29). Once SMEs reach the limits of their current production possibilities, employing part-time students with analytical knowledge expands a firm's know-how and therefore its absorptive capacities for new knowledge. However, this knowledge must be incorporated into work routine, which is troublesome.

Offering internships was another way to employ students from universities and gain access to new scientific knowledge: "We also want students, because we need highly educated employees, with potential, because we need this quality [of knowledge]" (F18). In contrast to part-time students, interns usually work on a small project on their own and contribute to a firm's innovativeness with suggestions for small improvements. They do this by offering access to analytical knowledge after they become familiar with a firm's routines. However, internships do not expand a firm's absorptive capacities through the provision of analytical knowledge in case interns leave the firm. Access to new knowledge and hiring new employees to expand one's combinatorial innovation mode are the main drivers behind offering internships. Costs can arise in financial terms and in terms of resources, as internships need to be trained at the work place.

Given an increasing level of integration, organizational barriers hamper innovativeness. In the case of the mechanism of 'employee knowledge', evidence was found that SMEs predominantly innovating in the DUI mode have a different way of organizing innovation processes than STI firms (C30, F29). Due to having fewer human and financial resources, a capability to organize innovation processes through pre-defined project work often

poses a problem for SMEs. This is especially true for SMEs with a non-academic workforce. For them, the implementation of analytical knowledge is hampered by less absorptive capacity and different innovation routines.

We found that one possible step to combine innovation modes is to acquire students for innovation projects or support bachelor or master theses. These offer STI knowledge to SMEs within a containable level of risks or costs associated with innovations. Nevertheless, these are the first steps towards integrating external academic actors into a DUI mode firm, with knowledge exchange across different organizations that pose a challenge to firms, a factor that can increase an SME's absorptive capacity in the long run.

According to our interviews, the size and variety of possible STI-related organizations is a challenge (F33). Hence, we conclude that a platform is required to initiate the first contact between DUI firms and students. Regional innovation consultancies promote job fairs or guide firm excursions to increase the visibility of local SMEs (C7, C13, C26). Bearing cognitive barriers in mind, we incur that advancing the integration of scientific knowledge into DUI firms becomes easier after an initiation phase of less formal contacts. At the same time, SMEs learn about innovation procedures at universities. One CEO stated that he would not even know where to start searching for the suitable contact person at universities, despite having undertaken an academic education in the respective region himself. He described that he is far from integrating university-knowledge (F33). However, the same SME acquired students from the local university for innovation projects in software development, indicating that there is potential for knowledge spillover from STI partners to this SME. Following this thought while considering interviews with regional innovation consultancies, we understand that they are aware of this specific problem (F27, C16, C4, C6). Being indirectly involved in the daily work of the SME, regional innovation consultancy has the function of prompting SMEs to see additional opportunities and emboldening the general manager to invest more resources in these special competencies.

3.4.3 R&D collaboration

The highest level of STI knowledge integration was through *research collaborations*. By definition, this mechanism was not used by firms mainly innovating through a DUI mode. University ties could be either formal or informal, where the latter was often established during a CEOs previous education at a university (F22). However, almost all STI firms

that have an R&D department or an R&D employee were also engaged in R&D collaboration with universities or research institutes.

Further, we also found some SMEs without R&D departments engaging in research collaborations. Nevertheless, they only occasionally undertake development activity, evaluate the learning effect from those collaborations as lower or engage in collaborations without scientific partners. These firms seem to be between firms that combine innovation modes and those that mainly learn by STI. They focused on one or a few development projects with external partners and use them as a substitute for internal R&D (F1, C7). They there motivated by the possibility to launch an own product for the first time (U1). Outcomes of R&D projects therefore offer the highest innovation output, in comparison with other mechanisms (F1). R&D collaboration is one way to reduce the financial costs of in-house R&D, although such collaborations do not mitigate the risks whether an R&D project delivers what it promises.

State-funding is one way to mitigate this risk. SMEs therefore use funding to co-finance R&D projects with universities and research institutes. While R&D collaborations often innovate in long-term projects (between 2 and 5 years), SMEs have to offer product solutions far more frequently (F19). Hence, R&D projects produce costs related to time and payment. Firms often do not consider the time spent by someone on their team on development as being worth the effort (F18, F36, F37). However, one CEO states: "What I did not manage to do during those four years was to bring the knowledge into our firm. […] now, in order to make it a product, we would need to invest into three to four years of development. […] that was too big for us, so we pulled out" (F37). SMEs combining DUI and STI processes struggle to absorb analytical knowledge that their partners possess and develop during cooperation projects. The lack of analytical knowledge results in a failure to introduce products of a higher technological complexity in the market.

Further, we identified cognitive, organizational and financial barriers related to R&D collaborations. One example of cognitive barriers to R&D collaborations is different mutual expectations. This highlights a gap between conjectures and actual knowledge about the other party's expectations regarding a research cooperation. Particularly in craft enterprises, we found a reluctance to contact professors and research institutes (C6, C17, C11, C4, C3, C16). The role of consultancies is to eliminate prejudices on both sides and bring together possible partners who would not have found each other without them. Thus, regional innovation consultancies occupied positions of trust and functioned as ice-

breakers between DUI firms and STI partners (C31). By contrast, SMEs neither addressed nor denied this reluctance (F18). Nevertheless, consultancies not only initiate knowledge exchange, but they also accompany meetings, establishing trust to ask questions and feel like partners at eye level (C3). Further, SMEs often have less experience with license negotiations. This leads them to employ regional innovation consultancies to offer security during these processes (C3).

The interviews highlighted the notion that perceived organizational barriers have become less important for R&D projects. Nevertheless, we could observe some obstacles that hampered the integration of STI knowledge through R&D cooperation. One SME adequately summarized that a facilitator who brings together possible partners and allows for a deeper understanding of thinking and working processes of both parties is required (F42). In case of an intended cooperation for a specific innovation project, evidence that consultancies channel knowledge exchange - and hence both parties profit from quick spillover effects - was found in both sample groups (F32, C3). The consultancies also have access to different regional industry networks, allowing them to connect STI partners with SMEs (C3). Thus, consultancies use various instruments to connect partners with different innovation modes: starting from an unspecific exchange via speed dating or cooperation markets at industry fairs to specific matchmaking of partners; for example, through the entrepreneurship service of the universities or small workshops (C19, C13, C12, F19, F32). Further, one SME states that the consultancies are also mediators in case of conflicts between collaboration partners. Different interests in the publication and secrecy of innovation results can hamper the collaboration between research organizations and firms (F34).

The main barrier to integrating STI into DUI mode firms using the mechanism of R&D projects is of a financial nature. Even SMEs with experience in combining innovation modes struggle to *finance* innovation projects. As our findings about the mechanism show, state funding can motivate firms to cooperate with STI partners. As funding of innovation projects is available on different scales, applications for funding are often too complex to complete them independently (F34, F36, F40, F18, F24, F27, F29, F31, F32, F30, F13, F10). This tendency increases with the scale of fund application. One STI firm explained: “You need these professionals, because funding programs are very diverse, it is a funding jungle, where you can’t climb through as an ordinary mortal” (F23). Another SME innovating mainly through STI processes adds that regional innovation

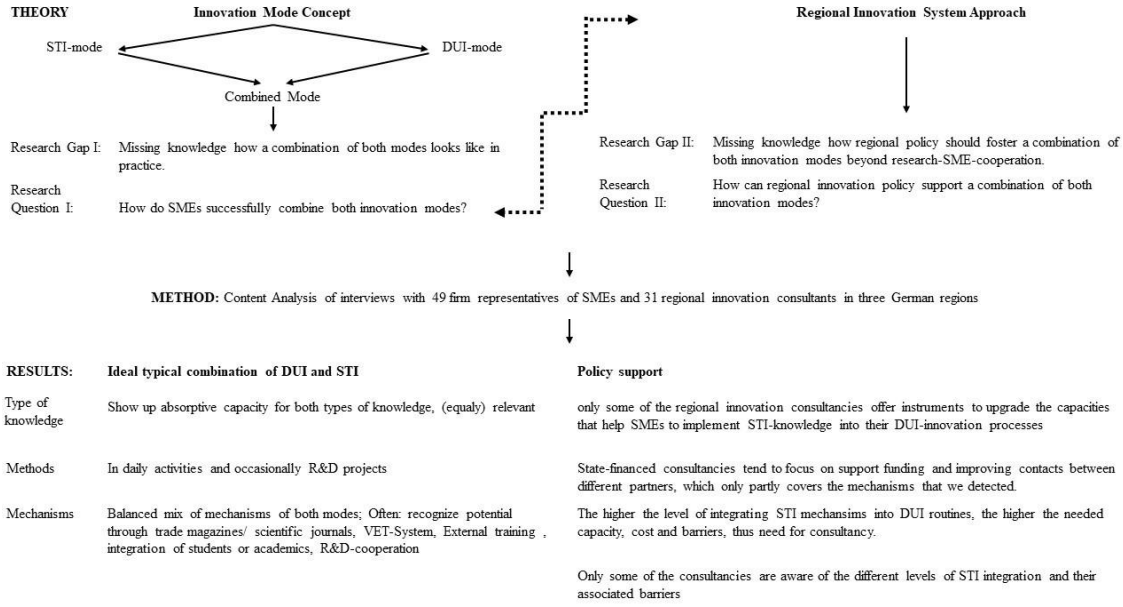
consultancies help SMEs to apply for funding, specify innovation ideas and therefore write better applications, which increases the chance of a positive response (F26). Especially more DUI-oriented firms with less experience in combinatorial innovation modes have trouble writing down their innovation ideas and introducing themselves as innovative per se (C31). As juries of funding applications often comprise academic members, SMEs must change and adapt their language and writing styles accordingly. In some cases, the innovation consultancies also take care of administrative accompaniments. According to the interviews with SMEs, they have less resources like time and knowledge to handle bureaucratic hassle, often needing an external professional to fulfill funding requirements (F36, F31). We learned from the interviews that support for funding applications consumes most of the work time of state-financed consultancies.

Further, most services of the regional innovation consultancies are free or much cheaper than those of private business consultancies. State-financed consultancy of SMEs reduces their resource disadvantages and makes professional consultancy possible for SMEs (C16). Nevertheless, we found self-reinforcing effects of positive applications and innovation prices: they "ennoble business plans", making it more likely to regain funding. Hence, local innovation contests conducted by regional innovation consultancies also boost application for funding at the state level (F25).

3.5 Discussion and implications

Based on qualitative interviews, we explored and described how SMEs manage to combine drivers of the DUI and STI mode. They incorporate STI mechanisms if necessary and suitable to their own or their clients' interests. We found several mechanisms through which SMEs make use of STI mode. Based on the literature review in chapter 3.2 and our empirical findings from the interviews, we argue that a combinatorial innovation mode is more than possessing R&D collaboration and integration of clients, suppliers or competitors; rather it comprises more nuanced and diverse mechanisms belonging to a DUI or STI mode as described in Section 3.4. However, the innovation mode concept can be seen as a continuum of mechanisms. The following graphic summarizes our findings and suggests a definition of an ideal typical combined mode.

Figure 7: Definition of an ideal typical combined mode and integration of results into research framework



In the following, we will discuss our findings in the light of the existing literature and deduce political implications to answer the second research question:

The role of codified knowledge as one part of STI mode was more complex than we initially expected. Although generally accessible for everyone, the practical application of codified knowledge requires a good deal of tacit knowledge, typically for DUI mode. This might be due to the fact that knowledge can hardly ever be totally codified (Johnson et al., 2002). Future research should shed light on the interaction between codified and tacit knowledge and the relevance for innovation modes.

Another important mechanism was the integration of employees with a scientific knowledge base to foster STI mode innovation. Firm-internal learning mechanisms were also addressed by Clarke und Winch (2006, S. 15), who explain that a firm's workforce competencies are raised by "the ability to apply theoretical knowledge in a practical context". While DUI mode innovations are usually about the "application of practical knowledge" (Toner, 2011), p.28), we suggest that a combination with the STI-mode requires parts of the latter - such as new technology or scientific insights - to be incorporated into working routines of DUI mode firms (Hirsch-Kreinsen, 2008) for better innovation and performance outcomes. This is fostered by the German vocational-

education- and training-System (VET) system using workplace learning (Solga, Protsch, Ebner & Christian, 2014). German firms invest in human resources that enable them to diffuse technology and incremental innovations (Toner, 2010). Hence, the VET system and its transfer of codified knowledge is important for SMEs as it allow firms to implement hands-on knowledge into their work routines without disrupting them (Toner, 2011). However, increasingly more VET institutions in Germany are closing down due to cost saving measures (Heidenreich & Mattes, 2019). In competition for qualified labor and skilled employees, spatial proximity to VET institutions could become a competitive advantage for firms in the long run.

Further, as the interviews have highlighted, SMEs that rely on experience-based knowledge and whose workforce have no university background face greater obstacles when trying to combine both innovation modes by using R&D collaborations. This is in line with Barker und Mueller (2002) who argue that innovation performance increases with the number of science or engineering degrees achieved by the CEO. It is experience-based knowledge that drives their incremental, user-centric innovations. When innovation policy values this alternative approach to innovations, one can question whether SMEs should receive funding for collaboration with universities, an institution that is often too far detached from their experience-based knowledge and not directly helpful in their DUI-innovation processes. We argue that given the technological trajectories (Dosi & Nelson, 2013), firms operate in either the DUI or STI mode and struggle to combine both ways of learning as they do not possess absorptive capacities related to the other innovation mode. This statement implies that there might not only be two faces of R&D (Cohen & Levinthal, 1989), but also routines of learning specific to the DUI mode that allow firms to capture DUI-specific knowledge.

Barriers to successful collaborations are a result of partnerships that possess different knowledge types that are difficult to combine. For firms trying to implement knowledge related to the other innovation mode, regional consultants can be helpful. Nevertheless, in line with Cooke (2014), we found evidence that only some of the regional consultancies are aware of the different levels of STI integration and their associated barriers. State-financed consultancies tend to focus on support funding and improving contacts between different partners, which only partly covers the mechanisms that we detected. We conclude that funding should also support innovation processes in DUI mode firms and their access to analytical knowledge. This could additionally build up the absorptive

capacity of SMEs related to technology, in comparison with an exclusive focus on collaborations with research institutes or universities. We found evidence that only some of the regional innovation consultancies offer instruments to upgrade the capacities that help SMEs to implement STI-knowledge into their innovation processes (C24, C20; C16).

A different role of regional innovation consultancies was found in East-Thuringia. In Jena, many SMEs are spin-offs of the university or research institutes. These SMEs already have a strong cognitive and organizational proximity, thus making it easier to implement STI-related techniques of innovating. This corresponds to Isaksen und Karlsen (2010), who argue that universities play a different role for each innovation mode: they can be a birthplace for spin-offs with an STI mode, whereas for DUI firms they educate the labor force and "upgrade" the existing industry (Isaksen & Karlsen, 2013). This is in line with Freeman (1994), who states that basic research affects industry foremost indirectly by supplying "young recruits with new and valuable skills and knowledge, rather than direct(ly), in the form of published papers" (Freeman, 1994, S. 469). Nevertheless, one should not simply assume that innovation policy must only improve the R&D infrastructure and connect DUI-firms with STI partners to increase their innovation output (Cooke, 2014). This might not have the desired effects if the absorptive capacities for analytical knowledge of a DUI firm are not increased at the same time. In accordance with firms' demands for several policy changes, we suggest going beyond state-financed cooperation with universities and instead aiding firms in finding their own path to new knowledge. One example is to stimulate recruiting academic employees to increase absorptive capacities and minimize cognitive and organizational barriers between DUI-firms and STI partners, as suggested by Isaksen und Nilsson (2013) for firms in Norway.

In the case of funding, we observe a new trend: the connection of large-scale enterprises with start-ups. The former have resources to invest in innovation projects but often lack creativity and agility. For start-ups, this matchmaking act helps to obtain small funding sums (around € 10,000), which are unavailable in Lower Saxony (C14, C18). While bureaucratic barriers to a successful application for state funding have become more pronounced, it becomes less attractive to SMEs, especially for small enterprises. Although this is a politically-known problem, it does not seems to have improved to date. As the funding system still partly fails to match SMEs' needs, we also point out that

cognitive and organizational barriers exist, which increases the importance of external facilitators.

Although we equate all regional innovation consultancies in this paper, in practice they have quite distinct functions in an RIS. Hence, no omniscient consultant exists. This indicates that strong cooperation between all innovation consultants in a region is necessary to improve the RIS (C4, C14, C21). Nevertheless, the success of connecting innovation partners is also related to the personality of the consultant, his/her capability to inspire confidence and accompany the knowledge exchange of DUI and STI partners (F3). Keeping this in mind, we argue that not every single regional innovation consultant has to offer instruments that cover all barriers. However, in times when innovation processes often cross traditional industry categories, it becomes especially important that regional consultancies interact, exchange knowledge and centrally coordinate offers between each other. It becomes obvious that regional innovation policy should not focus exclusively on firms' knowledge exploitation and research institutions' knowledge exploration systems but also on their own subsystem of 'supporting actors'. The awareness of their own subsystem tends to be less well developed among regional innovation consultancies.

3.6 Conclusion

In this paper, we have explored how SMEs combine different innovation modes and how and why regional innovation consultancies affect these processes. We interviewed 80 firm representatives and regional innovation consultants in Germany. The results show that DUI and STI mode processes have to be understand as a continuum, and thus it should be decided case by case where on the continuum a firm is placed. The patterns of mechanisms used to integrate STI-mode into DUI routines seem to be not industry-specific and sorted by the complexity of knowledge integration, whereby the three following mechanisms were found: i) use of codified knowledge (trade magazines, scientific journals), ii) use of employee knowledge (VET system, employee training, hiring external staff), and iii) R&D collaborations. A higher level of integration of STI-mechanisms into DUI-routines is accompanied by a stronger need for absorptive capacities and higher costs as well as cognitive, organizational and financial barriers. At this point, regional innovation consultants can affect a successful combination. Thus,

regional innovation policy is not restricted to financial services; rather it can also support SMEs through matchmaking and reducing cognitive barriers. Hence, we advocate strengthening policy activities that help to overcome the identified barriers, instead of focusing only on university technology transfer.

Finally, there are limitations related to our methodological approach, as well as a need for further research. Due to the nature of our qualitative research, we cannot generalize our findings in any statistical sense. We have explored theoretical relations among different constructs and underlying mechanisms and derived a model of how SMEs combine innovation modes. These theoretical relationships must be tested quantitatively to be reliable for a larger population.

4 High innovativeness of SMEs and the configuration of learning-by-doing, -using, -interacting, and learning-by-science: a regional comparison applying Fuzzy Qualitative Comparative Analysis.

Author: Tatjana Bennat

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Abstract

This paper proposes a holistic approach for investigating high innovation performance in SMEs by comparing different German regions. Invoking insights from the innovation mode concept and existing literature on regional innovation, we apply a Qualitative Comparative Analysis (QCA) of 47 interviews with SMEs to show that high innovativeness is based on a bundle of conditions summarized as mechanisms of learning-by-doing, -using, -interacting, and learning-by-science. The results indicate that only parts of the DUI mode, in combination with the STI mode, can explain high innovativeness. This has implications for managers as well as for innovation policy, highlighting that there is no universal "best way" to become highly innovative.

Keywords: DUI, STI, innovation mode, combinatorial knowledge

4.1 Introduction

Innovation is a primary source of competitive advantages and therefore an important research topic in economic geography. According to contemporary innovation concepts, the innovation process is based on many feedback loops among users, researchers and innovators (Kline & Rosenberg, 1986). This interpretation also stipulates that innovation need not be the result of scientific research-and-development (R&D) per se; rather, it also occurs through co-creation with users, suppliers or via firm-internal learning. Knowledge generation involves a variety of actors (Asheim et al., 2016), also driven by unique regional framework conditions (Boschma, 2005; Strambach & Klement, 2012), indicating that knowledge and innovation processes have become increasingly complex, interactive and cumulative. Jensen et al. (2007) conceptualize two fundamental ways of innovating: the "Science, Technology and Innovation (STI) mode" and the "Doing, Using and Interacting (DUI) mode". However, studies on innovation modes are inconclusive as to which mode (or combination) might be the most effective for innovation performance (Haus-Reve *et al.*, 2019; Apanasovich, 2016; Nunes and Lopes, 2015; Parrilli and Heras, 2016; Parrilli and Elola, 2012). Debate continues as to whether DUI and STI are complements or substitutes (Haus-Reve *et al.*, 2019; Apanasovich, 2016; Nunes and Lopes, 2015; Parrilli and Heras, 2016; Parrilli and Elola, 2012). Furthermore, little is known about the individual components of DUI-mode learning. Previous studies treated "DUI" as an abstract shell of learning mechanisms covered by diverse and interchangeable variables (Trott and Simms, 2017; Trippl, 2011; Aslesen *et al.*, 2012; Nunes and Lopes, 2015). However, we argue that it is worth breaking the DUI mode into its core mechanisms to learn what constitutes the causal "recipes" for organizational learning that lead to high innovation performance in a specific region.

This question is addressed in the context of innovation activities in small- and medium-sized enterprises in three German regions. Invoking insights from the innovation mode concept and economic geography literature on regional innovation, we propose that high innovation performance does not depend on specific conditions, but rather on a specific configuration of conditions—that is, high innovativeness is based on a bundle of conditions summarized as mechanisms of learning-by-doing, -using, -interacting, and learning-by-science.

The complexity of innovation activities necessitates a research design that allows for extending, modifying or revising theoretical structuring and hypothesis during the

research process (Mayring, 2002) and thus, a circulation between theory and method. During innovation processes, complex and diverse mechanisms come into effect. A qualitative comparative analysis (QCA) is an instrument able to deal with such complexity (Rutten, 2020b).

QCA is a set-membership analytical instrument appropriate for complex configuration analysis (Ragin, 2009). This method uses Boolean algebra rules to provide combinatorial explanations for small-N analysis (Amenta & Poulsen, 1994). Thus, it expects causal heterogeneity, assuming that different condition combinations (i.e. learning mechanisms) may influence a specific outcome (high innovativeness), rather than individual conditions per se (Ordanini, Parasuraman & Rubera, 2014). Hence, this paper intends to contribute to the question of which combinations of learning mechanisms lead to high innovation performance in SMEs by applying a QCA, which is a relatively new instrument in this field as well as in economic geography.

A deeper understanding of how SMEs learn and transfer knowledge into innovations is extremely important for adjusting innovation policy to the needs of SMEs (e.g. Isaksen and Karlsen, 2013; Coletti, 2010; Cooke, 2014; Aslesen and Pettersen, 2017). Thus, this paper holds implications for: a) SMEs themselves, and how the focus on specific configurations of learning can help find an effective innovation strategy. However, the analysis also shows alternative, potentially successful "recipes" for high innovation performance, reducing the risk of implementing putative "best practices" that do not fit a firm's setting; b) regional innovation policy searching for instruments to foster innovation activities in SMEs; and c) measurement of innovations based on DUI-mode learning.

This paper intends to answer two research questions:

1. Which configuration of learning-by-doing, -using, -interacting and learning-by-science leads to high innovation performance in SMEs?
2. How and why do these configurations differ at a regional level?

This paper is organized as follows: Section 4.2 presents the conceptual framework and introduces possible conditions for high innovation performance. After presenting the research design and QCA procedure in Section 4.3, findings are reported in Section 4.4. Section 4.5 discusses the findings and implications. Finally, a conclusion is made.

4.2 Theory and literature review

Underlying theoretical assumptions for this QCA are based on the innovation mode approach and regional innovation models such as regional innovation systems and relational approaches, and on earlier empirical findings of innovation research and our own findings from previous analyses of the same interview material. This is necessary practice for QCA as its causal claims rely on interpretation, which is based on triangulation with substantive empirical and theoretical knowledge (Rutten, 2020a). A core element of QCA is to analyze possible necessary and/or sufficient conditions for a specific outcome in order to reveal causal complexity. This paper aims to analyze innovativeness, which we define as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD, (2005), S. 46). Selection of conditions expected to explain the outcome are guided by theory and former case knowledge, constituting an iterative process of model-building (Amenta & Poulsen, 1994; Greckhamer, Furnari, Fiss & Aguilera, 2018). Thus, for model-building, different ways of innovating are identified and described in the following, introducing the four condition variables expected to explain high innovation performance: learning-by-science, learning-by-doing, learning-by-using and learning-by-interacting. The configurational rationale of conditions is explained below:

4.2.1 Learning in the STI mode

According to Jensen et al. (2007), different processes of idea-finding and innovation processes exist: STI and DUI mode of innovation. Closely related to the knowledge base approach (Asheim & Gertler, 2005; Manniche, 2012), both leading to innovation performance.

The STI mode relies on production and exploitation of scientific knowledge usually codified and based on know-what and know-why. This analytical knowledge is usually developed by searching and researching (Manniche, 2012) at universities, by R&D departments, or in cooperation with research institutions (Johnson et al., 2002). Traditional innovation research often used patent or R&D investment data to measure *learning-by-science* (Grillitsch et al., 2019). However, current research shows there are further mechanisms used to integrate scientific knowledge into innovation processes, like seeking analytical knowledge through trade magazines or scientific journals, training

employees or integrating academics, up to R&D collaboration with research organizations (Alhusen & Bennat, 2020). Thus, learning-by-searching is not only tied to internal R&D departments, high-tech sectors or larger firms. It is also used by small and medium-sized firms. Rather, a firm's absorptive capacity to learn from scientific knowledge and to innovate through an STI mode seems to be in the foreground. However, the STI mode of innovation has been generally associated with production of radical innovations (Nunes & Lopes, 2015).

4.2.2 Learning in the DUI mode

In contrast, innovations in the DUI mode are based on the application of mostly tacit and synthetic knowledge with a focus on know-how and know-who (Jensen et al., 2007; Johnson et al., 2002). Learning is more informal and conducted through doing, using and interacting. However, the definition and operationalization of the core learning mechanism of doing, using and interacting are inconclusive. Jensen et al. (2007) proposed a holistic concept of the DUI mode, explaining that learning-by-doing and -using both "involve interaction between people and departments" (Jensen *et al.*, 2007, p. 684). Nevertheless, most quantitative studies aim to measure DUI innovativeness based on a firm's internal or (more commonly) external interactions (Apanasovich, 2016a), using indicators of either learning-by-doing, -using and -interacting as representative for the DUI mode of innovation (see for overview Alhusen *et al.*, 2019; Parrilli and Heras, 2016; González-Pernía *et al.*, 2015). Nevertheless, the learning mechanisms of DUI differ in many aspects (e.g., actors involved, firm-internal and -external processes, and usefulness at different stages of innovation processes).

Therefore, it is worth breaking the DUI mode into its core learning mechanisms, according to the detailed definition of what constitutes each learning facet suggested by Alhusen et al. (2019):

Learning-by-doing is defined by learning from experienced workers as well as organizational structures fostering employee involvement in innovation processes (Arrow, 1962; Thompson, 2010). However, not only formal organizational structures, but also informal institutions like openness to learn from trial-and-error or an innovation-friendly culture influence learning-by-doing (mimeo, 2020). It is strongly associated with firm-internal interacting, (i.e. knowledge creation and sharing mechanisms inside a firm). Firm-internal interacting is therefore conceptually close to learning-by-doing but is sometimes considered a separate learning process in the literature (Apanasovich, 2016a).

However, we conflate these two mechanisms in order to emphasize the differentiation between firm-internal and -external learning.

Learning-by-using is defined as learning from customers or final users of a product or service who report the experience of using the product or service (Rosenberg, 1982), or who approach a firm to invent a product or service aligned with their specific needs (Alhusen et al., 2019). Such feedback provides the basis for knowledge accumulation and innovation opportunities from outside the firm. Firms use this learning mechanism to modify or re-design existing products/services or to develop new ones (Alhusen et al. 2019; Rosenberg 1982). Thus, integrating users can vary across a spectrum from "just stating an idea" to "active involvement in the innovation process and cooperation".

Learning-by-interacting is the product of firms' external interactions with suppliers, competitors, firms from other sectors, consultancies or industrial associations (Alhusen et al., 2019; Apanasovich, 2016; Johnson, 2010). Thus, external interaction captures all external, non-science-based actors who are not customers. This interaction includes informal and formal exchange of ideas and cooperation in innovation processes.

Innovation outputs of the DUI mode are often new customer-specific products or incremental in nature due to cost reductions or quality improvements (Hippel, 2005).

4.2.3 The configurational model of high innovativeness

Since the seminal paper of Jensen et al. (2007), the main tenet of the literature on innovation modes is that a combination of both modes leads to higher rates of innovation output (Apanasovich *et al.*, 2016; Apanasovich *et al.*, 2017; Chen *et al.*, 2011; Fitjar and Rodríguez-Pose, 2013; Fu *et al.*, 2013; González-Pernía *et al.*, 2015; Jensen *et al.*, 2007; Nunes and Lopes, 2015; Parrilli and Heras, 2016; Thomä, 2017). Also, the literature on innovation collaboration mentions that a various partners may provide different types of knowledge, enhancing firms' innovation potential (Strambach and Klement, 2012; Cooke, 2012; Bennat and Sternberg, 2020). Combining scientific and supply-chain synthetic knowledge thus fosters firm-level innovativeness, and different knowledge types are mostly regarded as complementary. However, Haus-Reve et al. (2019) criticize that those studies only focus on additive rather than multiplicative effects of combining STI and DUI. Their analysis of Norwegian firms revealed a negative interaction between scientific and supply-chain collaboration for product innovation, implying that they are substitutes rather than complements. These findings challenge the dominant tenet

asserting the benefits of combining different knowledge types. Nevertheless, their analysis only includes collaborations with actors having different knowledge bases, influencing product innovation. It remains unclear whether a combination of DUI and STI learning mechanisms (which are more than collaborations as discussed in the former section) will also point in the same direction. Former cluster analyses report that the combination of innovation modes is connected with higher levels of innovation performance. However, its definitions, the indicators used (especially for DUI), and interpretations still differ. In sum, multiple ideas exist regarding what constitutes a combinatorial innovation mode.

There is a scarcity of studies that could answer the question: Which concrete learning mechanism contributes to high innovativeness? Again, it is worth differentiating between the learning mechanisms of DUI due to their substantial differences in actors involved and applied innovation micro-processes (Alhusen et al., 2019). However, as the original idea of the DUI mode is a holistic view of mechanisms, we expect a strong interdependence between learning-by-doing, -using and -interacting. This expectation is also based on our previous studies of the analyzed SMEs, indicating that ideal types of innovation modes hardly exist in practice. This aligns with Isaksen und Karlsen (2010), who argued that innovation modes are not found in pure forms (Aslesen & Pettersen, 2017; Holtskog, 2017), but it is unclear whether this implies that "doing more of all" is a successful strategy for innovation in SMEs (Haus-Reve *et al.*, 2019).

Based on these theoretical concepts and previous empirical research, our research framework posits that high innovativeness depends on four learning mechanisms (learning-by-searching, learning-by-doing, -using and -interacting) implying the following general propositions:

Proposition 1: Disparate configurations of conditions are equifinal in explaining high innovativeness.

Proposition 2: The same condition can either foster or inhibit high innovativeness, depending on how it is configured with other conditions.

Innovation processes are therefore complex, while micro-processes seem to influence each other. Nevertheless, there exists a bias in theory and policy-making that neglects innovation developed through a DUI mode, which may partly be explained by the STI focus on innovation measurement (Jensen *et al.*, 2007; Laestadius, 1998). This can be

observed, for example, in the trend of technology transfer activities, the continuous improvement of R&D infrastructure, and political trials to connect DUI firms with STI partners to increase their innovation output (Cooke, 2014; Isaksen and Karlsen, 2010). Without an internal R&D department, learning-by-science is less likely to occur (Amara et al., 2008; Cohen and Levinthal, 1989). Therefore, the integration of STI into non-R&D firms is an important goal of current innovation policy, actively effecting innovation processes (e.g. BMBF, 2018). Furthermore, state-financed regional innovation consultancies can be important interacting partners in DUI mode innovation processes: giving advice for improving firm-internal innovation processes, establishing connections with other actors, counseling during funding applications and increasing firms' visibility through hosting innovation awards and network events (Alhusen *et al.*, 2019)

Hence, we assume that political authorities have been—and are increasingly—designing regional framework conditions. This assumption aligns with the literature on regional innovation systems (RIS) (Asheim *et al.*, 2016): Highlighting the role of regional policy in innovation processes, research from this field calls for tailor-made support strategies, recognizing the existing regional innovation structure (Martin *et al.*, 2011) and its historical contingency (Asheim *et al.*, 2011). Furthermore, the given R&D infrastructure, as well as regional financial incentives and subsidies, does differ between regions. This is also true for regional facilitators, competencies and networks. That means, being embedded in a specific region, firms' locations may also influence innovation processes, strategies and finally, the applied bundle of learning mechanisms. But it is not geographical concentration alone that might explain regional innovation processes. Rather, its conceptual connection with social spaces manifested in institutions (Lenz & Glückler, 2020), networks and communities might complete the argument of regional innovation. According to the relational approach to economic geography, the focus on micro-level interactions of individuals as principal agents of knowledge creation highlights the connection of social and physical spaces (Bathelt & Glückler, 2018). From this relational perspective, location determines access to local and global knowledge. For example, at research centers, campuses, conference venues or cultural facilities, physical and social spaces become connected through the co-presence of individuals, allowing the exchange of tacit knowledge through face-to-face communication (Rutten, 2017). Thus, hosting those venues, a diverse economic and social-culture and further characteristics of social spaces like shared norms, values, routines and trust informally coordinate the

mechanism of knowledge exchange. Clearly there are different approaches to explaining regional innovation. However, they all share knowledge exchange, and thus innovation processes might differ between regions. Therefore, we assume these regional differences are also visible in configurations of conditions, ending in Proposition 3:

Proposition 3: Configurations of conditions explaining high innovativeness differ between regions.

4.3 Method

4.3.1 Sampling of cases

Sampling in qualitative research does not purpose representativeness of findings for (larger) populations. Rather, cases are deliberately selected for constructing a corpus of empirical examples for studying the phenomenon of interest. The sample should capture the variation and variety in the phenomenon under study as far as possible (Flick, 2018). Therefore, a more "loose design" (Miles and Huberman, 1994) is appropriate when theoretical concepts are under-developed (like the innovation mode concept), with openness and flexibility as needed (Flick, 2018). The original goal of sampling was to cover multiple possible DUI micro-processes. Therefore, we followed a purposive sampling strategy seeking cases that assert themselves as innovative. The sample of interviews was not originally intended to meet the purpose of QCA, which would be to find cases covering all possible combinations of conditions. However, this instrument also worked well for our sample. Only two interviews lacked information about all conditions we tested; those were, consequently, excluded from the QCA procedure.

Hence, 47 interviews with firm's representative of SMEs are included in the QCA procedure. The face-to-face interviews were collected between February 2018 and October 2018 in the three German "planning regions" (*Raumordnungsregionen*)[8] of Goettingen, Hanover and East Thuringia[9] to cover three different RISs. The regions all include metropolitan areas, implying they are "organizationally thick" (Isaksen and Trippl, 2017, p. 125) RISs. They are characterized by a high number of SMEs, albeit they

[8] Functional division of analytical grids in Germany based on districts and commuting flows.

[9] Interview Sample: Goettingen: 17 SMEs; Hanover: 15 SMEs; East Thuringia: 15 SMEs

are orientated at different specializations of the economic structure. Furthermore, they all contain universities and research centers, permitting local collaborations with STI partners. For more details about regional specificities, see Figure 4 (page 52).

The sample of cases is non-industry-specific in order to reveal patterns of learning mechanisms not exclusive to particular industries (see List of Interviews). First, we identified SMEs that presented themselves as innovative. This was achieved through: a) extensive website analysis; b) snowball sampling, since interference between the cases could be negated (Schreier, 2007); and/or c) suggestions of regional innovation consultancies. Interviewees were asked to explain, in detail, what kind of innovations were achieved and how innovation takes place in their companies. Anonymity was ensured for all interviewees. After theoretical saturation (Glaser and Strauss, 1967), using the transcribed interviews, core processes important for the innovation output were examined via content analysis (Mayring, 2010) and ascribed to theoretically derived categories of each innovation mode. For example, statements regarding research cooperation with universities were categorized under STI-mode activities, and statements about knowledge exchange with suppliers were categorized under DUI-mode activities—more specifically, "interacting" according to each mode's theoretical definition (see for further information (mimeo, 2020)). Most SMEs studied displayed mixtures of processes: STI-mode activities and DUI-mode activities. Consequently, the researcher was familiar with all cases and their micro-processes. We thus gained advanced case knowledge through this analysis before beginning the QCA.

4.3.2 Qualitative Comparative Analysis

QCA ties together qualitative and quantitative characteristics (Kraus, Rigtering, Hughes & Hosman, 2012) originally developed for social and political science (Ordanini et al., 2014). However, the practice has also gained attention in innovation research and economic geography for investigating complex phenomena (Kraus et al., 2012; Ordanini et al., 2014; e.g. Rutten, 2019; Valaei, Rezaei & Ismail, 2017). QCA offers insights into which factors (or combinations) are relevant to explaining a specific outcome. By helping to increase the understanding of complementarities and substitutes in configurations (Fiss, 2011; Kraus et al., 2012), QCA can provide new insights for the discussion of combinatorial innovation modes described in Section 4.2. Advantages of QCA over standard inferential statistical methods include its ability to include combinatorial or conjunctural theories, whereby standard statistical methods face problems of degrees of

freedom or multicollinearity. It is open for causal heterogeneity and addresses the problem of "limited diversity" indicating which combinations of conditions empirically exist and which do not. Further, it offers a causally profound discourse about sufficient and necessary conditions (Amenta & Poulsen, 1994).

As a set-theoretic method, QCA conceptualizes both outcome and conditions as sets, being able to establish logical connections between conditions and outcome. It offers "rules that summarize the sufficiency between subsets of all the possible combination based on their causal conditions (or their complement) and the outcome" (Kraus et al., 2012, S. 17). Each rule represents an equifinal causation to the outcome (represented by the word OR). Thus, QCA does not test effects of independent variables; instead, it employs Boolean algebra to examine relations between an outcome and all binary combinations of causal conditions (Kraus et al., 2012).

Thus, QCA aims to find (combinatorial) conditions which simply describe all cases. Causal explanation follows from substantively interpreting empirical patterns on the basis of case-based and contextual knowledge. Thus, observed cross-case regularities must be checked by the question: How and why does conditions' presence make the outcome possible (Ragin, 2008; Rutten, 2020a)? Analysis of sufficient and necessary conditions is at its base. A condition is sufficient if no case exists where the condition is present, but not the outcome. That is, the configuration of conditions is a logical subset of the outcome. Sufficiency is, therefore, violated by cases presenting a condition (X) and the absence of the outcome (Y) (X,~Y cases) (Rutten, 2019). A condition is necessary if there is no case presenting the outcome but not the condition. That is, necessity means that all cases with the outcome also have the condition, but not all cases with the condition also have the outcome. That is, the condition is a superset of the outcome. Table 5 defines necessary and sufficient conditions:

Table 5: Evaluation of necessary and sufficient conditions

Condition is…	Condition X	Outcome Y	Evaluation
necessary	0	0	Allowed (but less relevant)
	0	1	Not allowed
	1	0	Allowed (but less relevant)
	1	1	allowed
sufficient	0	0	Allowed (but less relevant)
	0	1	Allowed (but less relevant)
	1	0	Not allowed
	1	1	allowed
Own elaboration based on Blatter, Janning & Wagemann, 2007			

However, due to the complexity of social reality and potential measurement error, QCA emits *consistency* rates to allow inconsistent cases before neglecting sufficiency (or necessity) (Rutten, 2019). It is good QCA practice to establish different consistency thresholds for necessity and sufficiency analyses. For necessity analysis, the threshold should be above 0.90, connected with a high coverage indicating that the potentially necessary condition is empirically relevant (Greckhamer et al., 2018). *Coverage* represents conditions' empirical relevance or importance for an outcome (Kraus et al., 2012). If X were a trivial explanation for Y, the coverage—and thus, the proportion of Y-cases covered by X-cases—would be very low (Rutten, 2019).

The application of QCA is structured by: i) definition of property space and development of set-membership measures, ii) evaluation of consistency in set relations, and iii) logical reduction. After QCA, solution terms are traced back to cases, which are covered from this solution's terms, including a subsequent content analysis after QCA procedure. This structure is used to present the results in the next section:

4.4 Results

4.4.1 The property space and development of set-membership measures

This study employs learning mechanisms involved in innovation processes in SMEs identified by the literature: learning-by-science, learning-by-doing, learning-by-using and

learning-by-interacting. Accordingly, the property space consists of all combinations of binary states (presence or absence) of the four conditions that could explain high innovation performance (i.e. 2^4 = 16 combinations).

Calibration—that is, the process of determining a case's membership in the sets of outcome and conditions (Ragin, 2008)—is a half-conceptual, half-empirical process (Greckhamer et al., 2018). Thus, the original micro-learning processes of each case must be transformed into membership scores reflecting the extent to which each SME can be considered a member of the different sets (outcome and conditions). Applying a fuzzy-set calibration approach[10], membership scores vary from 1 (full membership) to 0 (full non-membership in the set), pinpointing qualitative states (Ragin, 2009). The score of 0.5 indicates the cross-over point and maximum ambiguity (Kraus et al., 2012), that is not assigned in practice. The calibration process requires substantial knowledge of theory (see Section 4.2) and cases to specify the applied breakpoints. This is given by the fact that interviewer and researcher are congruent and that the same interview material was previously subjected to content analysis. A sign of quality in QCA procedure is transparent calibration. Therefore, the breakpoints (Table 6) will be explained and clarified through interview quotes:

Table 6: Calibration of conditions

Condition (learning mechanism) is…	1	regularly used for innovation processes
	0,8	often used for innovation processes
	0,6	now and then used for innovation processes
	0,5	*not affecting innovation processes that much*
	0,4	seldom used for innovation processes
	0,2	applied but not (jet) used for innovation processes
	0	not used at all.

[10] Instead of a binary crisp-set QCA conventionally based on Boolean algebra, where a case is either in or out of a set, with 1 indicating membership and 0 indicating non-membership. Fuzzy sets extend crisp sets by allowing membership scores in the interval between 0 and 1 (Ragin, 2017).

For calibrating the first condition ‘learning-by-science’, we included statements about use of scientific journals, implementing scientific theory, scientific training of employees or learning from academics, and R&D cooperation with universities or research institutes. Further, the evaluation of those processes and “how much” was learned was considered for scoring.

The following quote represents a score of 1:

> “I have researched around many topics and earned great methodological competencies. […] This big data idea was born during my PhD. […] we are able to do predictive maintenance or condition monitoring, because we were integrated in many scientific research projects before. […] I’m still close to my doctoral adviser. We meet regularly, organize events together and discuss how we can bring together research and practice. […] We also publish together, which is an important source for this firm, because […] the original idea is to bring together science and practice. […] university is also an important pool for new employees.” (F32)

To calibrate the second condition ‘learning-by-doing’, we extracted statements from interviews regarding learning through development or integration of new technology or machinery (hands-on-learning), training employees, openness to learning from trial-and-error, perceived innovation culture, and internal knowledge exchange. Clearly, for the scoring decision, it is necessary to include not only the presence of a learning mechanism, but also its evaluation for innovation processes.

The following quote represents a score of 0.8:

> “I implemented a helpful error culture. R. and I, we bluntly tell each other if we see something foolish, give feedback and thereby develop further. We follow this American thinking: ‘let’s quickly fail and then quickly learn.’ To develop products the market needs, I need both error and feedback. And then the openness to learn from them.” (F19)

The following quote represents a score of 0.2:

> “We have to do advanced training. I perceived this as a lot. […] If we want to apply for funding for a customer, we need to be listed and therefore, we have to

do advanced training. […] From the point of used methods or computer programs we are not very innovative…" (F30)

'Learning-by-using' was calibrated through information about the importance of customer interaction for innovation processes and whether the firm actively sought customer feedback.

The following quote represents a score of 0.6:

"Interviewee: [The innovation was developed] because of clinical necessaries. There where undesirable side effects. […] we also ask customer about satisfaction during treatment process via questionnaires. […] depending on the idea we also build prototypes.

Interviewer: Do you also integrate customers in prototype testing processes?

Interviewee: No." (F22)

To calibrate 'learning-by-interacting', we analyzed statements about suppliers' roles, interactions with non-competitor firms from the same sector, firms from other sectors, private and state-financed consultancies, and networks used for innovation processes. Statements about competitors were excluded, because we found an overall pattern in the interview material indicating that competitors were less important for innovation processes. This can be partly explained by Germany's current uncompetitive economic climate (Alhusen et al., 2019).

The following quote represents a score of 0.4:

"Interviewer: Are there other actors playing a role for novelty processes? Suppliers?

Interviewee: No.

Interviewer: Consultancies, banks?

Interviewee: No, neither. [We got ideas for novelties] through interaction with colleges, industry fairs or trading magazines." (F22)

According to the definition of innovation in Section 4.2, the outcome's calibration includes all innovation types (product, process, marketing, and organizational), whether

they are radical or incremental. Because our sample of cases only includes firms describing themselves as innovative, we have no information about cases which are not innovative. Due to this sampling peculiarity, we are unable to calibrate data for not being innovative (presence vs. absence of "innovative" outcome). However, it was possible to differentiate between levels of innovativeness. Thus, the cross-over point of 0.5 indicates the threshold between high innovativeness and average innovativeness, as our sample only includes SMEs which, at least, adapt innovation generated by others, which we ranked at the bottom of innovativeness (see Table 7).

Table 7: Calibration of the outcome

Firm….	1	regularly implements innovations	Indicates high innovativeness
	0,8	often implements innovations	
	0,6	now and then implements innovations	
	0,5	*Innovation processes are more than a single event*	
	0,4	implements one own innovation	Indicates average innovativeness
	0,2	Invents own innovation, but market implementation is still unclear	
	0	adapts innovation from others, but does not invent own innovations	

After calibration, a matrix is displayed, characterizing all cases after their scoring in each condition as well as the outcome (see Appendix III). All subsequent steps are based on this matrix.

4.4.2 Evaluation of consistency in set relations

The next QCA task is evaluating whether a condition is necessary for the existence of the outcome. Adhering to Greckhamer et al. (2018), we applied a threshold of 0.90 for consistency. We applied this analysis for all cases together using fsQCA software. Results show that neither the presence of all conditions chosen nor their absence (highlighted with ~) are a necessary condition to explain the "high innovativeness" outcome. Table 8 represents consistency and coverage rates for all cases together. Rates for learning-by-doing and learning-by-using are relatively high and near 0.90. However, this may indicate that learning-by-doing and -using are highly important for high innovativeness, but not necessary.

We analyzed configurations for the absence (negation) of the outcome separately. Thus, the occurrence of high innovativeness and average innovativeness (which represents the negation of high innovativeness) may constitute two qualitatively different phenomena. Analysis reveals that also no condition is necessary to explain average innovativeness. For all cases, ~interacting and ~sti appear very important, but their rates remain below the 0.90 threshold, indicating that the relationship is not symmetrical, as the presence of learning-by-sti and learning-by-interacting is not necessary, nor even particularly important, for the presence of high innovativeness.

Table 8: Analysis of necessary conditions

Condition	Consistency	Coverage
doing	0.835	0.773
using	0.835	0.779
interacting	0.734	0.850
sti	0.741	0.858
~doing	0.468	0.765
~using	0.439	0.710
~interacting	0.612	0.739
~sti	0.583	0.704

In the following, we evaluate which configuration may be regarded as sufficient for high innovativeness. Based on membership scores, sub-set relations can be analyzed by the truth table using Boolean algebra (Ragin, 2008). The truth table (Table 9) represents all logically possible configurations of these conditions' presence and absence; we have 16 configurations (rows). The "number" shows the case frequency, with membership above 0.5 in that corner of the vector space (Ragin, 2017). A threshold of at least one case is applied (Greckhamer et al., 2018). The "outcome" indicates which configurations lead to positive results. Outcome was defined as "true" (1 = consistent subset of the outcome) if consistency was above 0.90, which is based on a substantial gap in consistency scores (Ragin, 2009). The truth table shows that only two of the 16 possible configurations of conditions for high innovativeness do not exist in the sample including all cases (so-called "logical reminders"). This yields seven "true" rows, seven "false" rows, and two logical reminders. Thus, rows with zero-cases must be deleted. However, they are included in

intermediate solutions, as the researcher can test different assumptions about reminders based on theoretical and case knowledge.

Table 9: Truth table of all cases together

Doing	Using	Interacting	STI	Number	Innovation	Raw Consistency
0	1	1	1	2	1	0.959184
1	0	1	1	1	1	0.956522
0	0	1	1	1	1	0.947368
1	1	1	1	13	1	0.928571
1	1	0	1	4	1	0.928571
1	0	0	1	1	1	0.913044
1	1	1	0	5	1	0.910448
1	1	0	0	1	0	0.882353
0	1	0	1	4	0	0.875
1	0	1	0	5	0	0.87037
0	0	0	1	1	0	0.853658
1	0	0	0	2	0	0.8144815
0	1	0	0	4	0	0.813559
0	0	0	0	3	0	0.74
0	0	1	0	0	delet	
0	1	1	0	0	delet	

4.4.3 Logical reduction

Next, the 14 configurations of the four learning mechanisms are minimized based on a Quine-McClusky algorithm (Rille-Pfeiffer, 2009). Reducing the truth table generates result terms, the easiest paths to explain the outcome. For analysis of high innovativeness of all cases, three equifinal configurations are found, which underline Proposition 1:

a) doing*sti

b) interacting*sti

c) doing*using*interacting

Table 10 summarizes full empirical results.

Table 10: Analysis of the truth table (intermediate solution with no assumptions)

	raw coverage	unique coverage	consistency
doing*sti	0.676	0.079	0.904
interacting*sti	0.626	0.029	0.926
doing*using*interacting	0.633	0.072	0.898
solution coverage	0.776978		
solution consistency	0.885246		

These solution terms are robust in the case of prime implicants (~doing*interacting vs. interacting*sti) and for the assumption that all conditions are present vs. no assumptions. The high solution consistency (above 0.88) underlines the model's strength. The high solution coverage (above 0.77) shows that many memberships in the outcome are explained by the solution terms. Raw coverage indicates that between 0.62 and 0.67 of memberships in the outcome are explained by each configuration term. The proportion of cases covered uniquely by a specific configuration is displayed by the unique coverage scores (memberships that are not covered by other solutions terms), which are always very low (Schneider & Wagemann, 2012). Thus, the first term (doing*sti) appears slightly more important for high innovativeness, as its raw coverage is the highest (0.67). No single condition is sufficient to explain high innovativeness; rather, combination with other conditions explains the outcome.

Analyzing cases covered by the configurations reveals that many have membership in multiple or all configurations, suggesting that learning mechanisms are complementary rather than competing explanations for high innovativeness. Terms a and b also include DUI and STI mechanisms, while term c covers only DUI components. Firms with membership in all configurations include cases possessing their own R&D departments or cooperating with universities or research institutes. However, they also scored high on DUI mechanisms, using those mechanisms at least occasionally for innovation activity, but with different weights. The configuration of *makers*' (term a) innovation processes relies on learning-by-doing and learning-by-science. This is not exclusively linked to firms with formal R&D departments. However, they were often members of firm-university cooperation. The *networkers'* (term b) configurations cover firms scoring high on learning-by-interacting with suppliers, for example, or with other inter-sectoral firms

and learning-by-science. The *DUIs'* (term c) configuration comprises theoretical components of DUI mode literature. *DUIs* innovate mainly through learning-by-doing, -using and -interacting. It does not mean that they are not familiar with learning-by-science, but it was less important for their innovations.

In other words, high innovativeness appears in different cases because of different causal "recipes," but for most highly innovative firms, all three configurations are logical equifinal explanations for their success. Table 11 gives an overview of case distribution, which can be explained by the solution terms.

Table 11: Distribution of cases covered by solution terms

Cases covered by…	East-Thuringia	Hanover	Goettingen	Total
soley maker	1	2	2	5
solely networker	1	0	2	3
solely DUI	0	3	2	5
maker & networker	1	0	0	1
all three solution terms	4	5	4	13

This distribution gives a first indication that regional differences may exist between the three sample regions. However, a regional QCA is fruitless, as the truth tables of each region differ, showing between six to eight logical reminders and different configurations, which are covered by cases. Because the truth table of all cases together displayed only two logical reminders, we must assume that the missing configurations for regional analysis were simply not being observed, although they exist in practice. However, this must not be evaluated as indicating too few cases for each region. According to Marx (2006), the proportion of variables to cases should be < 0.33, which means in our case, five variables (four conditions and one outcome) are acceptable for at least 15 cases per region. Thus, a regional QCA would likely show divergent solution terms, but this cannot be interpreted as indicating different regional mechanisms. Therefore, a subset analysis was performed to check whether the overall configurations are also consistent subsets of high innovativeness for each region.

Subset analysis revealed that overall solution terms are indeed also consistent for each region (see Table 12).

Table 12: fsQCA output regional subset analysis

	Outcome Innovation	Consistency	Raw coverage
Goettingen	doing*using*interacting	0.9394	0.5962
	interacting*sti	0.9412	0.6154
	doing*sti	0.9444	0.6538
Hanover	doing*using*interacting	0.8250	0.7500
	interacting*sti	0.8571	0.6818
	doing*sti	0.8421	0.7273
East-Thuringia	doing*using*interacting	0.9600	0.5581
	interacting*sti	1.0000	0.5814
	doing*sti	0.9333	0.6512

However, consistency rates for East Thuringia were extremely high (nearly 1), while for Hanover, raw coverage was higher than for Goettingen and East Thuringia. This can be explained by the number of cases calibrated as highly innovative, but not covered by the three overall solution terms (three cases each in Goettingen and East Thuringia; two cases in Hanover). Thus, QCA did not reveal regional differences, which does not mean they do not exist.

The analysis for average innovativeness (~innovative) for all regions reveals three equifinal solution terms (~using*~interacting; doing*~using; ~using*sti) at 0.78 solution consistency and 0.65 solution coverage. Although those quality criteria are still acceptable, this indicates that the mechanisms chosen are better explanations for high innovativeness than for average innovativeness (see Appendix III). It confirms Proposition 2: that the same learning mechanism can either foster or inhibit high innovativeness, depending on how it is configured with other conditions.

4.5 Discussion of QCA results and subsequent case analysis

Results reveal that multiple processes can explain high innovativeness in SMEs (Proposition 1) and that individual learning mechanisms can foster or inhibit high innovation performance (Proposition 2). Regional subset analysis revealed that configurations of learning mechanisms explaining high innovativeness are also consistent for sampled regions. This study presents new insights into how learning mechanisms, and thus, innovation modes are interrelated, adding an alternative explanation for the (partially) inconclusive literature on combinatorial innovation modes. Results show that only parts of DUI mode together with STI mode can explain high innovativeness. No path was found which indicates that all four learning mechanisms together lead to high innovation performance. Rather, parts of DUI, together with learning-by-science, as well as DUI alone are sufficient conditions for high innovativeness in our sample. However, no learning mechanism was identified as a necessary condition.

Firms covered by all three logical equivalent configurations either integrated R&D cooperation at their innovation processes or maintain R&D departments, detached from firm size (as we also count for R&D departments if at least one person was responsible for innovation processes) as well as firm age. However, a pattern emerged from interview material: all those firms followed an innovation-friendly strategy (even if it was informal, which is quite often the case in SMEs (mimeo, 2020) and integrated an innovation culture, allowing for trial-and-error learning. Nevertheless, some SMEs with formal R&D departments were not covered by all three solution terms. Thus, we conclude that it is not the R&D department per se; rather it can be an indication for an innovation-friendly mindset and the ability to think in innovation processes.

These strategies, of course, do differ between firms inter alia because of different environments (Martin et al., 2011), histories (Asheim, 1996; Asheim et al., 2011), experiences, markets or CEO characteristics (mimeo, 2020). Therefore, there is no universal "best practice" to become highly innovative, implying that it is not "doing more of all" (Haus-Reve *et al.*, 2019), which explains high innovation performance. Nevertheless, no evidence was found that "doing more of all" explains the negation of high innovativeness, which is average innovativeness. It was, rather, explained through the absence of learning mechanisms.

4.5.1 Prototypical innovation mechanism

QCA reveals only that learning mechanisms must be present to explain high innovativeness, but not whether those mechanisms are also combined in practice. As we allowed interviewees to explain mechanisms of different innovation projects of their firms, scoring did not represent their use in one specific innovation project. In order to interpret the essence of the configuration for high innovativeness, QCA solution terms are qualified by another case-level qualitative analysis. Thus, cases are identified which are covered by each configuration term, complementing a cross-case analysis to report prototypical innovation mechanisms as suggested by Greckhamer et al. (2018) and Ragin (2017).

Further content analysis of *makers'* interviews (doing*sti), showed that learning-by-doing and -science are indeed combined for a specific innovation. However, those cases typically integrated students (as interns or academic employees) to bring scientific knowledge into the firm, connecting it with expertise of older, more experienced workers at the firm; R&D cooperation with research institutes was evaluated as unhelpful.

> "Yeah, we had some R&D cooperation projects. But it was a rather bad experience. We did that two, three times. […] Our experience is that the result is better if you do it by our own […] I think, it is helpful to have a great mixture of experienced older employees and new knowledge of young employees which they carry out of university. Mixing this knowledge is the optimum." (F38)

This has implications for innovation consultancies as well as managers. It is not R&D cooperation itself that fosters high innovativeness. Rather, in more "doing-orientated" firms, integrating students and academics as sources of scientific knowledge proved more fruitful.

Content analysis of *networkers* (interacting*sti) indicated that those firms participated in ZIM projects[11] with other firms and research institutes. Thus, we found little evidence in

[11] "ZIM" ("Zentrales Innovationsprogramm Mittelstand") stands for "Central Innovation Program for small and medium-sized enterprises (SMEs)." Funded by the Federal Ministry for Economic Affairs and Energy, it aims to foster innovative capacity of SMEs. It is

interviews that this connection would exist without this specific promotion instrument of German policy. In all cases, covered solely by this solution, learning-by-science was explained as a helpful knowledge component during the innovation process. However, these firms were relatively close to scientific research (e.g., their customers were universities or their innovation was also based on scientific tests of food-safety or bio-natural gas, for example). Therefore, policy instruments fostered this specific interaction, even if in ZIM projects it is not necessary to include a research institute. This influence, however, is a double-edged sword, as this interviewee explained:

> "Yes, we are always interested in those [ZIM] projects, however, especially for this bio natural gas project, the market goes up and down. Funding pops up and disappears, abolished, then restricted and in the end it is unappealingly. This is a heavy problem, sometimes a great pity, if you have invested much money before, also, public resources. And then banks bounce down. From my point of view these are senseless wastages." (F44)

Firms solely configured as *DUIs* had no formal R&D departments, being start-ups and mature firms from service and producing sectors (also high-tech), with only some CEOs having university backgrounds. Interviewees highlighted that learning-by-doing, -using and -interacting are indeed combined during innovation processes. Furthermore, according to interviewees, these learning mechanisms are also used in that order during innovation processes. The two following quotes represent this assumption:

> "Innovation? Baby steps! I prefer small steps. Big, brilliant invention, like long ago, reclusive at the basement, then after four years development a market release. This is not working anymore. Product life cycles are too short. This means, small steps, find someone for a proof of concept, interact with customers, and then start development in coworking with others." (F20)

> "We start from the beginning. We developed an audit method to analyze the real pains of a specific firm. […] Which problem do they solve and will this problem

Germany's largest innovation program for SMEs. For further information, see Bundesministerium für Wirtschaft und Energie (2020).

be relevant in the future? This is the first step. Afterwards, we analyze if the firm indeed resolved this problem. This means: do they offer the right product, do their processes hit the needs. […] This is what I do before matchmaking […]. And then we search for start-ups, which could face this problem. If we found some, we connect the firms and organize projects." (F19)

However, we found evidence that this was true for product innovation, but not for organizational innovation. The latter were often the result of learning-by-doing alone.

4.5.2 Regional Analysis

Regional subset analysis revealed that the three overall solution terms are also consistent for each region. Hence, all solution terms include elements of DUI-mode learning mechanisms. This has an important implication for policy support, which nowadays strongly focuses on an STI mode. Thus, learning-by-science is neither necessary nor sufficient to explain high innovativeness in sampled SMEs. Regional innovation policy and consultancy should also recognize their own important role as supporters of firm-internal learning as well as fostering interaction.

Although QCA did not uncover regional differences, some regional peculiarities are found during content analysis of the interviews. Thus, according to Proposition 3 - that results differ for regional analysis - we must assume this proposition is only partially proven by this method.

For example, interviewees in East Thuringia often highlighted the importance of learning-by-interacting and learning-by-science, which is indeed among the solution terms the QCA revealed: Analysis of East Thuringia interviews revealed that this is partially explained by the historic structuring of the economy in former East Germany. Interviewees described East Thuringia as still shaped by specialization in optics and medical technology paired with a great variety of applied research institutes. This also has consequences for qualified employees because universities, applied research centers and firms are familiar in related clusters. "Talking the same language" and operating in related markets, coupled with the history of combination structure of economy in the former GDR, means that many SMEs already know - and therefore trust - each other. Further, some interviewees highlighted that many start-ups (or spin-offs) settle near applied research centers. This aligns with the argument of relational approaches emphasizing that shared norms, values, customs, habits, routines, trust, or further forms

of relational proximity effectively "glue" individuals together and work as "lubricants" for knowledge exchange (Malecki, 2012), and highlights the informal nature of social space (Bathelt & Glückler, 2018). However, some formal activities of fostering knowledge exchange were also found. There was evidence in the interviews that in East Thuringia, the concept of "cluster" is highly charged with technology and innovation topics, strongly supported by regional policy. Therefore, many local networks can potentially foster knowledge exchange and cooperation. One interviewee explained three different ways that R&D cooperation starts:

> "Often research institutes approach us about specific cooperation […]. This is one possible way. A second way is that cooperation is fostered through networks often resulting in research projects. And the third way are, for example, ZIM Projects; there two firms work together with one research institute, developing a specific technology […] We do all three ways." (F34)

This quote suggests that innovativeness simply happens to a firm. However, it is hardly determined by its agents. Due to the emergent nature of causality, a learning mechanism's presence lets firms act in ways that make high innovativeness possible. Due to some inconsistent cases, it might be that unobserved causes may negate the willingness/ability of firms to innovate, even when sufficient conditions are present. Causality enables, but never forces an outcome (Rutten, 2020a, 2020b). This is also the case for interacting partners like business consultancies:

> "Yes, we have got a specific contact person, who is capable. I think highly of him. He has many contacts, knows everything, what is actually happening and always an interesting interacting partner. This is less institutionalized, it is personal […] the person matters. Either the person is helpful or not." (F20)

Hence, not only the regional offer of innovation consultants, but also their personalities differ between regions. As for Hanover, the overall evaluation of policy support, consultancies and infrastructure enabling cooperation, innovation and growth was perceived as mostly positive by company managers; policy support was particularly criticized for Goettingen:

> "The office for economic development just woke up in the last years, now supporting start-ups and so on; 10 years ago, there was nothing! […] Because

> their consultants are quite old and have been working there for a long time. […] They know nothing more than the internet." (F4)

Nevertheless, this quote also shows the dynamic of regional peculiarities which can enable or inhibit specific learning mechanisms. However, the firm managers interviewed who actively sought to be innovative were capable of compensating for this aspect (e.g., by using economic associations for network activities).

4.6 Conclusion

To define the causal "recipes" for organizational learning that lead to high innovation performance in specific regions, we applied a QCA of 47 SMEs in three different German regions.

The core findings should be consulted for regional innovation policy and managerial questions, which are: (1) No condition is solely necessary nor sufficient to explain high innovativeness. It is rather the combination with other conditions that explains the outcome; a concentration on one learning mechanism would be less successful. (2) There was no evidence that all four learning mechanisms together led to high innovation performance. Rather, parts of DUI, together with learning-by-science, as well as DUI alone, were sufficient conditions for high innovativeness in our sample. This implies that a policy focus on the STI mechanism would neglect a DUI mode of being innovative, which is equally promising for becoming highly innovative. (3) Many cases had membership in multiple or all configurations, which suggests that the learning mechanisms are complementary rather than competing explanations for high innovativeness. (4) Finally, the overall solution terms were also stable for different regional contexts, which, however, does not mean that regional peculiarities do not exist, which is an important insight for policy makers when transferring concepts from one region to another. This analysis first showed insights into differences in regional innovation processes. However, a further QCA with more nuanced regional sampling is needed to evaluate whether these peculiarities can be also found in regional solution terms, explaining high innovativeness. Thus, a more tightly designed sample strategy (Flick, 2018) or a larger sample would be useful for applying regional QCA. The latter, however, would especially make a subsequent content analysis, and therefore the integration of QCA results into interview contexts, challenging. Nevertheless, QCA can

also expand economic geography methods in order to reveal a different view on regional innovations, and is a helpful method for deepening the understanding of the innovation mode concept.

5 The underestimated role of top executives in DUI mode of innovation: CEO characteristics and their influence on innovation activities in non-R&D-based small and medium-sized enterprises.

Author: Tatjana Bennat

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Abstract

Studies in various fields have highlighted the influence of top-executives on firm performance, including innovation activities. Especially for SMEs, this influence seems to magnify, with most SMEs innovating not through R&D, but rather through learning-by-doing, -using and -interacting (DUI mode). Lacking formal organizational structures for innovation activities, a chief executive officer's (CEO's) capability and willingness to enhance employee commitment and integration takes on greater importance. However, little is known about how, and through which characteristics, the CEO effects DUI mode innovation activities. Thus, we connect the DUI mode concept with business management research. The results show that the CEO acts as a particularly important moderator and mediator between DUI learning mechanism and innovation performance. This improves theory concerning innovation processes in SMEs and imply that regional innovation policy should also focus on offers that strengthen an innovation-friendly cognitive base of CEOs who show appreciation for firm's internal and external ideas.

Keywords: Innovation mode, upper echelon perspective, innovation culture

5.1 Introduction

Small and medium-sized enterprises (SMEs) innovate differently in comparison to larger firms (Wee & Chua, 2013). Due to having fewer resources, they mainly innovate through daily internal knowledge exchange (learning-by-doing), the integration of customers into their development processes (learning-by-using) or (informal) cooperation with their suppliers or other firms (learning-by-interacting). Jensen et al. (2007) aggregate these learning mechanisms into the doing-using-interacting (DUI) mode of innovation, which is typically found in SMEs. While larger firms have resources for combining the DUI mode with innovation activities, based on formal research and development (R&D) or research cooperation (learning-by-science, technology and innovation, STI), many SMEs use less formal ways of enhancing their knowledge (Brink et al., 2018; Rammer et al., 2009), often solely relying on a DUI mode of innovation.

Nevertheless, according to management researchers, it is widely accepted that innovation is tied to knowledge-management processes. For example, Nonaka und Takeuchi (1995) characterize innovative firms as knowledge creating. Hence, an organization's capacity to innovate is at least partially based on its ability to manage and utilize the knowledge of its individual employees (Andries & Czarnitzki, 2014), regardless of whether this is formal or informal (Alhusen & Bennat, 2020). Researchers from various disciplines, such as management (Ahn, Minshall & Mortara, 2017; Andries & Czarnitzki, 2014; Barker & Mueller, 2002; Georgiadis & Pitelis, 2012; Papadakis & Bourantas, 1998), sociology (e.g. Hammann, Habisch & Pechlaner, 2009) or psychology (e.g. Peterson et al., 2003), have investigated the factors that drive these learning processes, finding evidence that the chief executive officer (CEO) plays a crucial role. For example, Hambrick und Mason (1984) construct an upper-echelons perspective, arguing that organizational outcomes, such as strategies and effectiveness, are reflected in the executive cognitions, values and perceptions of a situation. Indeed, empirical evidence has shown that firm size is negatively related to a CEO's ability to influence organizational outcomes because the decentralized nature of larger firms leads to a distribution of decision-making powers and inertia (Papadakis & Bourantas, 1998). Conversely, in SMEs, which are often under private ownership, the CEOs have greater freedom in decision-making, and often show personal responsibility for the success of their own enterprise (Hammann et al., 2009). Therefore, they have a more direct impact on the firm's activities than the CEOs in top management teams in larger firms.

Because larger firms have recourse to implement organizational structures, such as R&D departments, their innovation activities often rely on a combination of a STI and DUI mode. Non-R&D-based SMEs innovate through more informal learning mechanisms, often solely through a DUI mode, strongly influenced by their top-executives. This influence is not mentioned in the literature on different innovation modes, however (see for overview Apanasovich, 2016). The innovation mode concept provides few insights into how these practices are applied and by whom they are shaped. Answers are missing to questions on how, and through which personal characteristics, CEOs influence the innovation performance of non-R&D-based SMEs. What role does the top-executive and their specific character play in DUI mode innovations that showcase employee knowledge and interactions? Insights could be used to improve the theory concerning innovation processes in SMEs. This is of great importance, as a firm's ability to innovate is significantly connected to growth, competitiveness and sustainability. Thus, the nimbleness and flexibility of innovative SMEs are an important policy target (Apanasovich et al., 2016). For example, the Organisation for Economic Co-operation and Development (OECD) highlights policy activities for fostering productivity in SMEs (Marchese et al., 2019). The aim of this paper is to examine how, and through what personal characteristics, the top-executive influences DUI mode innovation processes in SMEs, thus improving the DUI mode concept using business management research.

By applying a qualitative content analysis of 41 interviews with representatives from SMEs and 31 regional innovation consultants in Germany, we found indications that the top-executive acts as a moderating and mediating factor between the DUI learning mechanism and innovation performance. This is a new insight, the previous innovation-mode literature not having addressed this topic at all, and management studies being, to a great extent, based on larger firms or not having referred to innovation processes. This work not only improves our theoretical knowledge about innovation processes in SMEs, but also has implications for: a) SMEs themselves, and the awareness of an innovation-friendly culture shaped by the top-executive; b) regional innovation policy searching for new instruments to foster innovation activities in SMEs; and c) the measurement of innovations that are based on DUI mode learning.

This paper unfolds in six sections. The Section 5.2 presents the theoretical background and a literature review. Section 5.3 contains the methodology this analysis was based on, followed by the results (Section 5.4) and a discussion of these in light of the existing

literature and the implications (Section 5.5). Finally, a short conclusion is provided in Section 5.6.

5.2 Theory and Literature Review

5.2.1 Learning processes and innovation modes in SMEs

SMEs usually have smaller or no explicit expenditure for R&D or R&D departments (Brink et al., 2018; Rammer et al., 2009). Nevertheless, they are able to introduce new products or processes. Rather they apply experience-based knowledge and creative thinking (Asheim & Coenen, 2005; Asheim & Hansen, 2009; Manniche, 2012). Based on the greater involvement of users and the co-creation of ideas with suppliers or other firms, a prominent recent contribution to the different types of knowledge-creating activities has been made by Jensen et al. (2007), who introduced the STI and DUI mode of innovation to explain the innovativeness of firms with regard to different ways of utilising internal and external knowledge (see: Apanasovich, 2016; Parrilli et al., 2016 for reviews).

Learning in the STI mode relies on the exploration and exploitation of technical and analytical knowledge (Jensen et al., 2007). This is usually codified and based on know-what and know-why, as developed in universities or by R&D departments, often in cooperation with other research institutions (Johnson et al., 2002). Thus, the basis of innovation in the STI mode are scientifically-trained workers and R&D investments (Isaksen & Trippl, 2017). Innovation outputs resulting from an STI mode are often more radical nature (Nunes & Lopes, 2015) and protected by patenting or publication (Cooke, 2014).

On the other hand, learning in a DUI mode is based on the application of mostly tacit and synthetic (experience-based) knowledge, with a focus on know-how and know-who (Jensen et al., 2007; Johnson et al., 2002). Shaped by its informal nature, such knowledge is conducted through doing i.e. learning from working experience (Arrow, 1962; Thompson, 2010), using i.e. feedback from users and their integration into the innovation processes (Rosenberg, 1982); and interacting i.e. with firms, suppliers and competitors, as well as other actors, such as consultants (Bennat & Sternberg, 2020; Jensen et al., 2007; Lundvall, 1985). Such innovation outputs are not only (incremental) product or process improvements, but also new customer-specific products (Hippel, 2005).

Bearing these two different ways of innovating in mind, it becomes clear that SMEs are a typical example of innovations not restricted to R&D-driven, science-based knowledge alone (Bennat & Sternberg, 2020). Recent contributions to the DUI mode of innovation have highlighted the importance of experienced and creative workers, as well as human resource management practices that foster the involvement of employees in the innovation processes of non-R&D-based SMEs (Apanasovich et al., 2016; Jensen et al., 2007; Nunes & Lopes, 2015; Parrilli & Heras, 2016; Thomä, 2017). Indeed, this is included in the innovation-mode concept, although this concept provides few insights into how these practices are applied and by whom they are shaped. The ability to manage and to utilise individual employee knowledge and knowledge exchange is strongly connected to a firm's ability to innovate (Andries & Czarnitzki, 2014). Thus, it is of great importance to study the possible moderators and mediators of the DUI mode learning process.

Whereas moderator variables specify the direction and/or strength of a relationship between a predictor and a criterion (in our case, learning-by-DUI and innovation performance), mediators indicate how and why such effects occur (Baron & Kenny, 1986). While the DUI mode literature highlights processes of learning among different stakeholders, we emphasize that the people are the 'real' medium, their learning processes playing an important role. According to business management studies, this is especially true for top-executives (Ahn et al., 2017; Andries & Czarnitzki, 2014; Barker & Mueller, 2002; Georgiadis & Pitelis, 2012; Hambrick & Mason, 1984; Hammann et al., 2009; Stum, 2009). Thus, the next section provides an overview of the studies that have referred to the influence of top-executives on firm performance and innovation processes.

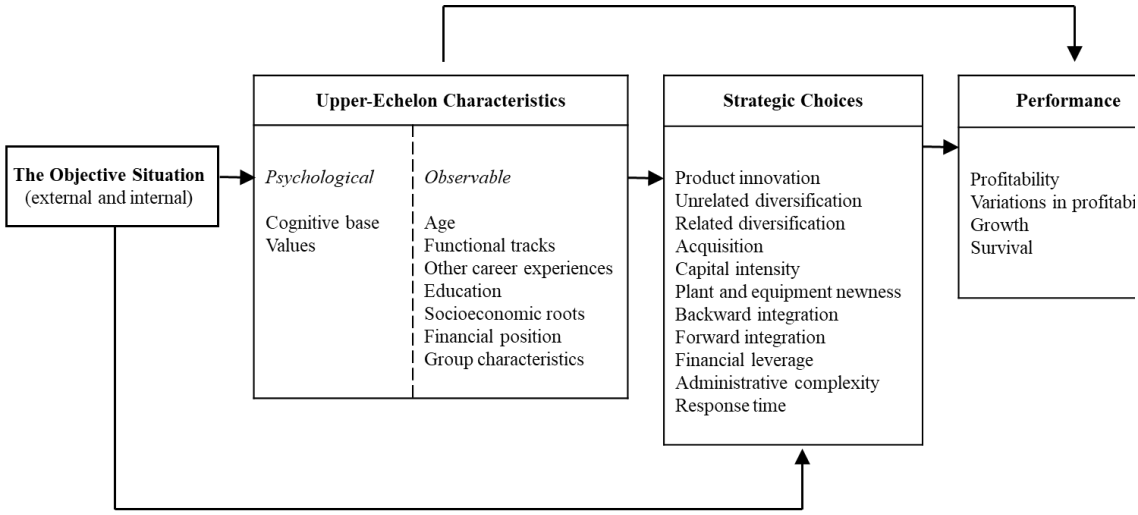
5.2.2 Top executives matter: Literature review

Over the last few decades, much research has been applied to answering the question, 'Why do organizations act as they do?' (Hambrick & Mason, 1984, S. 193). Research has shown that an organization's capability to innovate is closely connected to its ability to utilize its knowledge resources. It is widely accepted that these knowledge management processes are manifested by aspects of human, organizational and social capital (Subramaniam & Youndt, 2005). However, researchers in this field have taken a rather narrow view of this concept. By focusing on components such as the education or experience of individuals and codified knowledge (e.g. patents or network partners;

Subramaniam & Youndt, 2005), it has often been overlooked that these are the results of individual decisions, ignoring the psychological determinants (Marcati, Guido & Peluso, 2008).

One central model that overcame this limitation was contributed by Hambrick und Mason (1984). Their article on the upper-echelon perspective has been quite influential on organizational (Andries & Czarnitzki, 2014; e.g. Georgiadis & Pitelis, 2012), psychological (e.g. Peterson et al., 2003) and entrepreneurship (e.g. Klotz, Hmieleski, Bradley & Busenitz, 2014) studies. Its core argument is that the executive cognitions, values and perceptions of a current situation influence the process of strategic choice-making, which in turn results in performance outcomes. Hambrick und Mason (1984) argued that strategic choices have a large behavioral component, consisting of a decision-maker's cognitive base (knowledge or assumptions about future events, alternatives and consequences). They are also influenced by their values, which can be defined as 'principles for ordering consequences or alternatives according to preference' (Hambrick & Mason, 1984, S. 195). Because situations are complex, the decision-maker creates a screen between the situation and their perception of it, the latter influenced by the individual's cognitive base and values. This in turn provides the basis for making a strategic choice. Observing cognitions, values and perceptions is difficult. As a consequence, previous upper-echelon research has been based on demographic proxies, such as age, functional background, education, experience or financial position (Carpenter, Geletkanycz & Sanders, 2004). Hence, the upper-echelon model has a dual role as both a theoretical framework and a method. Figure 8 outlines the original upper-echelon model.

Figure 8: Hambrick and Mason's (1984) upper-echelons perspective of organisations



Many studies have been performed to validate the upper-echelon model. In analyzing the correlation between CEOs or top management teams and performance outcomes, using a variety of quantitative measures, most of the studies have pointed out a significant connection between the 'observable' executive demographic characteristics and firm performance, without focusing on psychological factors (see for overview Carpenter et al., 2004). Over time, the original upper-echelon model has been enhanced by the addition of direct and indirect variables to the model. For example, Papadakis und Bourantas (1998) showed that top-executives' characteristics significantly influence technological innovation (product and process), but that a firm's aggregated internal and environmental variables are more important. Nevertheless, in the case of new products, the top-executive's characteristics outweigh structural and environmental factors.

An important contribution was made by Peterson et al. (2003) in opening up a 'black box' of psychological characteristics. They focused on the effect of personality variables, as captured by the 'Big Five' personality traits (agreeableness, conscientiousness, extraversion, neuroticism, openness), which is a current methodology for examining personality differences. In analyzing 17 CEOs of large American enterprises by applying a q-sort methodology, which is a 'useful tool to quantitatively code qualitative data' (Peterson et al., 2003, S. 800), they quantitatively showed that the CEO's personality was related to top team management group dynamics, which in turn is related to organizational financial performance. Further, top-management-teams, which can be characterized by

intellectual flexibility, optimism and cohesiveness, performed significantly in terms of greater income growth. These results imply that a top-executive's personality is statistically connected to team dynamics, and thus the performance of the organization (Peterson et al., 2003).

Also, Kirton (1976) analyzed how the cognitive style of a person influences their decision-making process, which contributes to answering the question about organizational leadership and why executives act as they do. Kirton's (1976) Adaption-Innovation Inventory (KAI) was developed to compare the style of problem-solving in individuals. Stating that everyone can be located on a continuum from an ability to 'do things better' to an ability to 'do things differently', Kirton (1976, p. 622) labeled the ends of this continuum 'adaptive' and 'innovative'. Adaptors are described as being concerned with solving problems rather than finding them, finding solutions that are approved, working with a high degree of accuracy, rarely challenging rules, being sensitive to upholding group cohesion and thus providing safety for the riskier operations of innovators. Innovators are described as seeming undisciplined, approaching tasks in an unusual manner, performing detailed work selectively, showing a dynamic capability to bring about periodic revolutionary change and being confident in generating ideas. Kirton (1976) developed an inventory consisting of 32 questions to help place an individual on this continuum. The KAI contributes to the understanding of organizational leadership, highlighting that one cognitive style is not better than another, with both adding value to organizational leadership (Stum, 2009). A correlation between the KAI and the Big Five personality characteristics has also been proved. Innovators have significantly higher levels of openness to experience and lower levels of conscientiousness than adaptors (Gelade, 2002; Marcati et al., 2008). Further, higher levels of extraversion have been noted in innovators, depending on the variables used for measuring this personality trait. However, it is still unclear whether top-executives of innovative SMEs exhibit a more innovative or adaptive style of problem-solving. How innovative must a top-executive of a non-R&D-based SME be if employee knowledge, customer ideas and suppliers or consultants are to be placed in the foreground of DUI-mode learning processes?

Most studies have analyzed large firms. However, for SMEs in particular, the top-executive should play an even more significant role in influencing performance outcomes. This can be reasoned by reference to the personal relationships common to the

organization and its members, the greater freedom in decision-making and contracting, the individual responsibility of the owner for the success of the enterprise, as well as the easier control of information (Hammann et al., 2009; Papadakis & Bourantas, 1998). Thus, we might expect that, especially in SMEs, the personality, values and demographic background of the top-executive would strongly influence business strategies and practices, and thereby the learning processes and innovation activities.

Recent studies focusing on SMEs have examined knowledge management processes, all concluding that the top-executive plays a major role. For example, Wee und Chua (2013) stated that the key source of knowledge creation is the CEO, who also influences knowledge management processes. More precisely, Andries und Czarnitzki (2014) explicated that 51% of the ideas for new products were made by the CEO, while for process innovation, employee ideas are crucial. It was also noted that a top-executive's attention to their employees and value-based human resources management practices leads to higher motivation and satisfaction of the employees, as well as better financial performance (Georgiadis & Pitelis, 2012; Hammann et al., 2009). These studies highlight that the CEO is an important source of innovative ideas in SMEs and that their influence on employee attachment to the firm is crucial. Nevertheless, none of these studies addressed the top-executive's personality.

Psychological approaches have also been discussed in entrepreneurial studies. For example, Marcati et al. (2008) pointed in a similar direction, finding that entrepreneurs with different tendencies to innovate have significantly different personality profiles. Obschonka und Stuetzer (2017) found evidence that an intra-entrepreneurial constellation of the Big Five personality traits, including high values for extraversion, openness and conscientiousness, and low levels of agreeableness and neuroticism, predicts entrepreneurial skill growth, motivation, self-identity and behavior in an individual. This personality pattern is also, on a regional level, connected with higher entrepreneurship rates and innovation activities (Fritsch, Obschonka & Wyrwich, 2019).

However, innovation activities in SMEs are not exclusively linked to the top-executive. Following the DUI mode concept, knowledge creation instead accrues through the integration of non-managerial employees, the customers and externals, such as suppliers or consultants (Jensen et al., 2007). Quantitative studies of CEO influence have highlighted the connection between personality factors and team performance (Peterson et al., 2003). As previous research has traditionally focused on larger firms that rely on

an STI mode of innovation, we argue that the influence of a top-executive involved with DUI mode innovation activities is even greater and more important for innovation output. Firms innovating in an STI mode identify specific departments to foster the innovation that are functionally and organizationally designed to produce innovations. Firms, and most often SMEs in general, relying solely on a DUI mode are reliant on a firm's internal and external knowledge exchange and employees volunteering for innovation projects, in addition to conducting the business operations. Therefore, the influence of the top-executive to foster employee integration and interaction with other stakeholders, and thus promote innovation activities, can be seen as a critical factor that impacts innovation performance in SMEs.

However, due to the quantitative nature of the studies referred to, there is still a need for the application of a qualitative methodology to contextualize the findings in relation to innovation processes in SMEs. Previous studies have shown the statistically significant connection between personality traits, specific personal characteristics and entrepreneurship or firm performance; however, they have not been able to explain *why* this connection exists in any detail. Qualitative studies are necessary to contribute to answering questions about how, and via which personal characteristics, do top-executives influence innovation performance in non-R&D-based SMEs. The insights obtained from our study will not only be used to improve the theory concerning innovation processes in SMEs, but also have significant implications for the measurement and improvement of innovation activities in SMEs in general.

5.3 Methods

Given the research gap identified above, we chose an exploratory qualitative approach, which is best suited for research that addresses "how" and "why" questions, and if a less appropriate theory exists (Eisenhardt, 1989; Eisenhardt & Graebner, 2007). A case study design helps to uncover the complex generation of new knowledge and a firm's internal combination process. Thus, we used qualitative interviews to analyze DUI mode learning processes.

Between February 2018 and October 2018, we conducted face-to-face interviews with 41 firm representatives and 31 regional innovation consultants or local business

development agencies [12] from the three German planning regions ('Raumordnungsregionen[13]') of Goettingen, Hanover and East-Thuringia. All the regions include metropolitan areas, implying 'organizationally thick' Regional Innovation Systems (Isaksen and Trippl, 2017, p. 125), but their economic structures are based on different specializations, and are characterized by a relatively high number of SMEs.

As the research interest was to find patterns between non-R&D-based innovation processes applied in SMEs that were not industry specific, we included SMEs from different industries and sectors (see Table 4: Overview of interviewed industries p.50). Thus, we do not imply that all the processes we allocated to the theoretical concept of DUI have to exist in all SMEs, regardless of industry or organization. Rather, we were interested in collecting all the gradations of the processes that related to DUI innovation output.

However, due to the theoretical concept of innovation modes, little is known about the core processes manifesting each mode of innovation. Thus, in a first step, we identified SMEs that presented themselves as innovative. This was achieved through: a) an extensive website analysis; b) snowball sampling, since interference between the cases could be negated (Schreier, 2007); and/or c) the suggestions of regional innovation consultancies. After theoretical saturation (Glaser & Strauss, 1967), we extracted the core processes that were important for the innovation output in each (SME) case. Then, we examined how these core processes could be ascribed to the theoretical assumption of each innovation mode. Thus, all processes connected with formal R&D departments, research cooperation or scientific knowledge were allocated as STI processes. Processes relying on learning-by-doing/using/interacting were summarised as DUI mode processes (see for further information Alhusen et al., 2019). Some important factors associated with innovation in SMEs were not covered by the theoretical concept of innovation mode, and were ascribed to "further important factors" (e.g. the influence of a top-executive on those processes). This allowed us to categorize every SME, if their innovation activities could be referred to an STI or DUI mode. Due to the idealistic nature of the typical differentiations between STI and DUI, however, the practice was more complex. Most of the SMEs studied displayed a mixture of processes, which we referred to one of the

[12] Interview sample: Goettingen – 10 RICs/18 SMEs; Hanover – 12 RICs/15 SMEs; East-Thuringia – 9 RICs/9 SMEs.

[13] Functional division of analytical grids in Germany based on districts and commuting flows.

theoretical innovation modes. Thus, we argue that the innovation mode concept cannot be understood in terms of dual categories, rather having to be seen as a continuum of processes. Based on our case study analysis, we argue that it is not possible to innovate solely based on a DUI or STI mode of innovation. Thus, innovating by STI (DUI) always involves some aspects of DUI (STI) mode learning processes (see Figure 5: Continuum of processes referred to DUI and STI mode of innovation p.53; for further information, see Alhusen & Bennat, 2020). For example, innovation based on STI would not occur if a researcher could not draw on their previous (scientific) experience and informal knowledge exchange. Thus, there must always be a small contribution of DUI in STI innovation. For DUI innovation we could not identify a single case which was not using any kind of STI process. Even if these processes were low-threshold like applying codified, analytical knowledge from trade magazines or academic interns.

Further, we extended the cases through interviews with representatives of regional innovation consultancies (private and government-financed) who were concerned with building up regional knowledge networks and increasing absorptive capacities in SMEs. We used this second group to compare insider and outsider views. Following Karlsen und Larrea (2018), we merged the context-related knowledge of the regional innovation consultancies, the experience-based knowledge of individual SMEs and the theoretical knowledge of the research team to co-generate a framework for DUI mode innovation activities, which is also adaptable to (regional) innovation policies. Due to our underlying aim to cover all gradations of DUI mode innovation processes, we argue that the SMEs were only capable of explaining their firms' specific innovation processes, whilst the regional innovation consultancies were able to identify a range of possible innovation processes in SMEs.

Starting with the theoretical knowledge of the innovation-mode concept, we summarized the core aspects of our research into two interview guidelines that consisted of open questions (Flick, 2017), one for the SMEs and one for the consultants. Questions about the top-executive's personality and the firm's strategy or innovation culture were not included in the main interview guidelines. Delving into these topics suggested an inductive manner, as the interviewees stated that the CEO was the key person for innovation activities in SMEs. The interviewees were asked to explain, in detail, how innovation (without R&D activities) took place. Anonymity was ensured to all the interviewees. Using the transcribed interviews, we conducted a content analysis

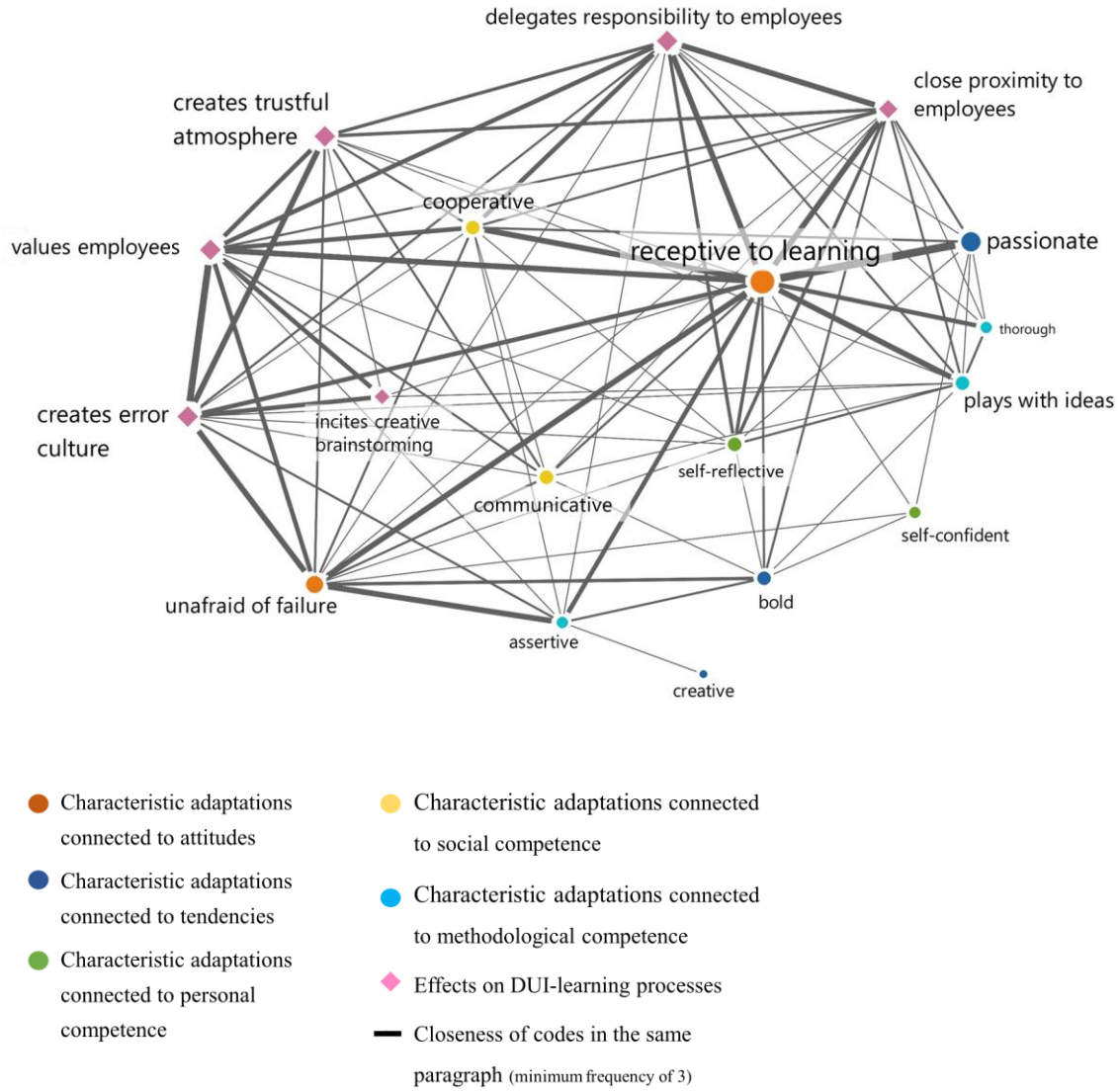
(Mayring, 2010), thus incrementally reducing the content of the interviews to statements relevant to our research questions. We used deductive categories for information that was related to our guideline questions, and inductive categories for information that was new to us such as information about the influence of top-executives. We further condensed the codings into summaries and inductively developed more nuanced subcategories. Those, in turn, were used for the analysis we based the results on. The typical characteristics of CEOs influencing innovation activities were directly mentioned by the regional innovation consultancies, and were inductively collected from the interviewed top-executives or key persons in the SMEs. In 36 cases, we interviewed the CEO, principal or entrepreneur of the SME, with only five cases where our interviewee was a member of the top management team. For convenience, we use the term 'CEO' for all interviewees of the 41 analyzed SMEs. As we did not directly ask the CEOs about their personalities, we deduced their characteristics from their answers, opinions and the manner in which they organized or evaluated the innovation activities in their own firms. This did not undermine our research, rather enabling us to differentiate between observable characteristics and how the CEOs thought they *should* be. We cite abstractions or statements based on SMEs with a 'F' and those from regional innovation consultancies with a 'C', followed by the number of the interview in accordance with our internal database.

5.4 Results

The interviews with the SME representatives and regional innovation consultants highlighted several aspects that explain how and why CEOs influence DUI innovation activities in non-R&D-based SMEs. Most of the interviewees described personal characteristics as being more important than demographic variables, such as age or education (C16, C23, C4, C19, C17, F19). A CEO's former experience (F21, F19) and 'gut instinct' were mentioned as the basis for decision-making (C14). This colloquially-described gut instinct mirrors the processes a decision-maker faces when being triggered by a specific situation. Due to the theoretical base of this content analysis like the upper echelon perspective, it is assumed that the perception of this situation is influences by the CEO's psychological characteristics. However, as we did not directly measure the personality traits of the interviewed CEOs, we were not able to give answers about their basic personalities, as covered by the Big Five. Instead, we analyzed their characteristic

adaptations. Characteristic adaptations summarize aspects of ones attitudes, skills, relationships, values, beliefs and cognitions (Obschonka & Stuetzer, 2017). Being quite malleable over a lifetime, characteristic adaptations are influenced by relatively stable basic personality traits (Obschonka & Stuetzer, 2017). Thus, characteristic adaptations are guided by the individual personality of a person, and arise from their daily interactions with their environment (McCrae & Costa Jr., 2008). They can be described as mid-level personality units, which are conceptually located between general personality traits (like the Big Five) and specific behavior (Buss & Cantor, 1989). With respect to our interview material, it was possible to dissect the answers of the CEOs in order to discern their characteristic adaptations, which were important for the DUI mode innovation processes. In the following, we present all the characteristic adaptations, as well as their practical connections to DUI mode learning activities, that were revealed in the interviews. After the analysis, the derived characteristics were cast as descriptions of categories used to define characteristic adaptations. Thus, the already existing descriptions of characteristic adaptations were used to structure the inductively worked out characteristics of CEOs from the interview material. The results from interview analysis could be sorted into skills, tendencies and attitudes. Figure 9 presents the contextual proximity of those characteristics and their influence on intra-firm learning mechanisms, which were explained by the interviewees as being crucial to DUI mode innovation output. Although the thickness of the connections between the nodes, as well as the size of the nodes, is based on frequencies, we have not interpreted this in a quantitative manner. Much more important is the interrelation between the characteristics themselves and with the processes relevant to DUI mode innovations. Figure 9 highlights the complexity of a CEO's influence on DUI mode innovation activities, and indicates that results should be seen as a CEO's interdependent constellation of characteristics.

Figure 9: CEO characteristics and their connection to DUI-mode innovation processes



5.4.1 Characteristic adaptations connected to attitudes

Two main characteristics were found that can be summarized as general attitudes that were revealed in the interviews as being important for DUI mode innovation activities (an attitude is an evaluation of an person, place or issue that influences thought and action; Perloff, 2017). The first was a generally open-minded attitude of the CEO that was connected to high *learning receptivity*. Many interviewees described or introduced themselves as being visionary (C25, C26, C29, C15, C18, C23, C9, F21, F20, F19, F2, F16), who liked to play with ideas or to think against type (C17, C23, C16, C19, C9). We

found a close connection between a generally open-minded attitude and the way in which hierarchy is experienced, with close proximity to employees and higher rates of delegating responsibility to employees producing flat hierarchical structures. Together with showing appreciation for their employees, this created an error culture, which was highlighted as being important for DUI mode innovation activities. Hence, a personal and informal connection between the CEO and their employees increased the motivation to participate in innovation activities in SMEs. According to the interviews, personal characteristics, such as learning receptivity and an open-minded attitude in the CEO, determined how they interacted with their employees, influencing their individual identification with the firm, the motivation to participate, and therefore the innovation culture of an SME (C24, C19, C9, F33, C13, C20).

The second general attitude we found was connected with the possibility of failure. The interviews highlighted the notion that an innovation-friendly CEO was *not afraid of failure*, rather valuing failure as an opportunity to learn and develop. This risk-taking propensity often co-occurred with willingness to learn, which is a key aspect of openness. One CEO put it clearly: 'Please, let's quickly fail, and then quickly learn.' (F19). We learned from the interviews that this attitude is directly transferred to the employees, creating an error culture and valuing employee work. Both were evaluated as crucial factors in generating creative ideas (C12, C19, C9, F21, F19, F8). Hence, characteristic adaptations, such as risk-taking, showed a reversed influence on innovation output. Content-wise, this was connected with an atmosphere, where employees had the freedom to try out new ideas. According to the interviews, this atmosphere tended to be more important than physical open space for developing innovations. Several interviewees explained that harsh leadership hampered employees' innovative ideas (C14, C18, C20, F19, F14). Thus, a CEO who is unafraid to fail is able to create a trustful environment.

5.4.2 Characteristic adaptations connected to basic tendencies

The second group of characteristics can be aggregated as the basic tendencies of a person's character traits or the inclination towards a certain type of behavior. Many interviewees indicated that innovative CEOs were passionate about their business, tending towards self-confidence, which in turn increased their energy and perseverance in innovation projects (C25, C30, C15, C23, C4, C7, F3, F5, F9, F16). It was also highlighted that passionate CEOs tended to have a high maker-mentality, unafraid to

invest ‘much blood, sweat and tears’. This was clarified by a CEO’s statement: ‘I am the development department, I, mostly on Sundays!’(F5). While innovation processes in the DUI mode can last for a long period of time, this passion seems to be very important for innovation output (C24).

A passionate character was strongly connected with a basic attitude to openness. Surprisingly, a *creative* character was not mentioned very often. One regional innovation consultant explained that neither the most creative or qualified CEOs led innovative businesses, but rather other characteristics, such as assertiveness and an efficient work style, were important. Team management and motivation were emphasized (C19).

The third characteristic adaptation connected to a basic tendency was to be *bold*. Contrary to the suggestion of some regional consultants who identified written long-term vision and strategic planning as being helpful to innovation processes, some innovating SME representatives implied that development plans were recorded, but not in the manner of knowledge management, such papers being hard to implement and maintain. Moreover, they would become redundant because of the close proximity between the CEO and all the employees (F8). Nevertheless, acknowledging innovation as a strategic choice, CEOs need to show courage and be bold in order to get rid of old and routinised structures and to build up innovative processes (C20). Therefore, being bold was contextually connected with a general failure-friendly attitude.

5.4.3 Characteristic adaptations connected to soft skills

The third group of characteristic adaptations can be summarized under the broad field of skills. Again, most of the interviewees described personal characteristics as being more important than demographic variables, such as age or education (C16, C23, C4, C19, C17, F19). Thus, in this section, we focus on soft skills, such as personal, social and methodological competencies, instead of professional competence. Personal competencies involve self-awareness and self-management, while social competencies concern contact with other individuals. Methodological competencies are connected to the handling of methods or techniques.

Starting with characteristics that can be aggregated under the topic of personal competence, we found evidence from the interviews that a CEO who is open-minded to ideas from others, such as employees, customers or other stakeholders, tended to also be

self-reflective (F25, F16). One CEO stated: 'If I am self-reflective, I am authentic: in this way, I can take my employees along [with me]'(F16). We also detected that CEOs who questioned current activities were more likely (in a qualitative manner) to change routinised processes and showed high flexibility (F35, C18), which in turn exerted a great influence on the innovativeness of the employees. A strong connection between the tendency to be passionate and the personal competence of being self-confident was also identified. Thus, a CEO, who is passionate about their business also tends to turn out to be *self-confident*, which in turn increases the energy and perseverance of often long-lasting DUI innovation projects (C25, C30, C15, C23, C4, C7, F3, F5, F9, F16, C24). Both characteristics were connected to the basic attitudes of openness and a lack of fear about failure.

Aspects of social competence could be selected. Highlighting the importance of a trustful atmosphere in DUI mode SMEs, the interviewees explained a connection between a generally innovation-friendly atmosphere and a *cooperative* CEO (C25, C26, C9, F2). A cooperative character was not only reflected in a high willingness to learn from others, such as employees, customers or other stakeholders, but also signified the value of the employees. A cooperative CEO was often described as delegating responsibility to their employees, which in turn increased their motivation and their identification with the firm. Both were summarized as being crucial factors in generating innovative ideas, as well as implementing alterations (F19, F8, F14, C29, F35, C20, F20). Cooperation was on the basis of DUI mode learning processes; hence, a cooperative CEO was described as being indispensable to innovation output. This also affects a firm's strategy around the extent to which they will cooperate with customers, suppliers or other firms, share resources, or integrate external consultants into their innovation projects. Furthermore, the forgiving and helpful nature of a CEO can encourage employees to experiment with new ideas and to speak out about the barriers that hamper production processes. Helping each other on some level was often described as occurring naturally by the interviewed SME representatives (F36, F4, F20, F17, F33). Further, a *communicative* nature was highlighted. According to the interviews, a communicative CEO integrates their employees into the decision-making process and demonstrates close proximity to the employees, resulting in a value-based relationship with them. This creates a trustful atmosphere in which employees are encouraged to state their own ideas (C9, C14).

Employee ideas were mentioned as being crucial to DUI mode innovation, being directly linked to firm-internal learning-by-doing activities.

Furthermore, characteristics referring to methodological competence were mentioned. A *thorough* and conscientious character was suggested as being helpful in implementing innovations or alterations (F32). For SMEs in particular, the CEO is the central point, where firm-internal information, customer demands and employees' creative ideas are consolidated. Consequently, in thinking holistically, the CEO processes this disparate information and decides to embrace or ignore an opportunity. The CEO is also responsible for allocating the resources for innovation projects (C17, C7, F34, F21, F37). One interviewee explained: 'They [employees] come up with new ideas every week and want to test new technology components for costumers. Sometimes I have to slow them down, because otherwise we would do innovation projects every week.' (F4). This indicates that the CEO plays a central role in SME innovation processes, directly deciding which ideas will be pursued. This aspect was often mentioned together with the ability to *play with ideas* or to think outside the box (C17, C23, C16, C19, C9), both of which are contextually connected with an open-minded attitude.

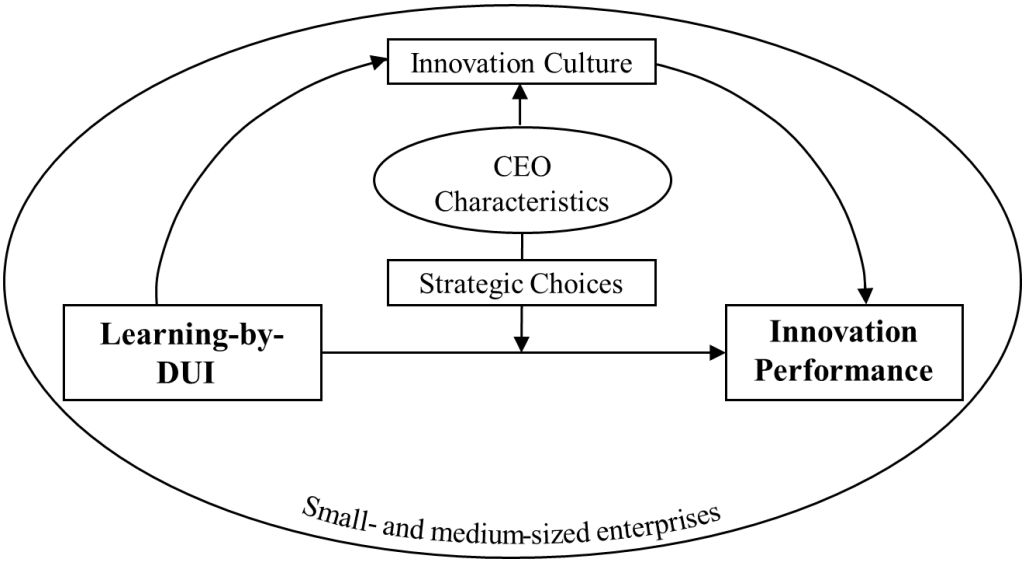
In addition, the CEO predefines a firm's strategy. According to one regional innovation consultant, the awareness that innovation is a strategic decision challenges CEOs in DUI mode firms (C20). CEOs of innovative SMEs were described as having an *assertive* personality (C19, F1), whilst at the same time showing sensitivity for employee and customer demands (C16, C14, F19).

To summarize, the CEO is confirmed as being crucial to the innovation process in non-R&D-based SMEs. The CEO influences DUI mode innovation processes directly, deciding on whether to pursue an innovative idea or neglect an opportunity. Consequently, we argue that the CEO moderates DUI mode innovations, acting like an on/off switch for the actual innovation processes. Thus, the CEO also navigates strategic choices in DUI mode SMEs; however, these strategies are, in most cases, not formalized. Formalization becomes redundant due to the close proximity between all the members of the firm.

Furthermore, an innovation-friendly attitude, integrative soft skills and values that foster non-managerial employee integration into innovation processes were exposed as being crucial in gaining new innovative ideas. Hence, not only strategies, but also the informal innovation culture of a firm, are shaped by the CEO's characteristics. Both strategy and

innovation culture tend to have a significant impact on SME's innovation outputs. Thus, the CEO's cognitive style and characteristic adaptations also indirectly mediate the mechanism of DUI-mode learning processes through guiding an informal innovation culture (see Figure 10).

Figure 10: Mediating and moderating influence of the CEO on DUI mode innovation



5.5 Discussion and Implications

The empirical analysis of the influence of top-executives on DUI mode innovation processes in non-R&D-based SMEs revealed that their individual characteristics moderate and mediate how learning-by-DUI results in innovation performance. Thus, coming back to the upper-echelon model, the character of a top-executive not only influences how strategy is selected, but also affects the innovation culture of a firm, giving answers about how and why learning-by-doing results in innovation performance.

The characteristic adaptations referred to an open-minded attitude were manifested by a high learning receptivity and a lack of fear of failure, these being the most emphasized characteristics in the interviews, and being strongly connected with team management and the innovation culture of the analyzed non-R&D-based SMEs. As for new processes, structures or products, divergent thinking and an open-minded culture become imperative, with the characteristics of the CEO being critical in eliminating prejudice (Ahn et al., 2017) because their attitudes influence a person's intention and concrete

behavior with respect to an object (Fishbein & Ajzen, 1975). As has already been shown for larger firms, team risk-taking and the intellectual flexibility of the team are strongly connected with the openness of a CEO (Peterson et al., 2003), and this may be critical in non-R&D-based SMEs. It is not clear how these manifestations of characteristic adaptations are connected to basic personality traits, such as the Big Five. However, we found further congruent results; for example, Marcati et al. (2008) demonstrated that openness to experience is the main personality trait of entrepreneurs, explaining more than 36% of the variance in their dataset. Thus, openness to experience has the strongest correlation to a general innovative cognitive style, as has been validated by Gelade (2002). Furthermore, our empirical study showed that a fearless attitude towards failure is connected to a trustful atmosphere and innovative culture. Team psychological safety is generated, in large part, by the atmosphere the CEO creates, and this is also strongly connected to team performance (Edmondson, 1999). Significant correlations have also been found between emotional stability and team cohesion and the intellectual flexibility of the team members (Peterson et al., 2003), as well as a general innovative cognitive style in entrepreneurs (Marcati et al., 2008). Because the innovation processes of a DUI mode often involve external partners, this will bring greater uncertainty than internal innovation, thus requiring a CEO who is open to taking risks (Ahn et al., 2017). By contrast, Peterson et al. (2003) found no significant correlation between neuroticism and team-level risk-taking.

A passionate and bold character was explained as being helpful in outlasting periods of uncertainty, as innovation processes can take time. Econometrical analysis has already shown that more extroverted leaders are correlated with a more interactive and energetic personality, and that they are more forceful in communicating their opinions (Peterson et al., 2003). Marcati et al. (2008) pointed out something similar. Gelade (2002), however, applied a meta-analysis, finding a between-study variance in extroversion and creative style. One possible explanation for this could be the use of different scales in that study. Thus, it could be a sign that some variables of extraversion are associated with innovators, and some are not. He suggested further research on the different facets of extraversion. Our study reveals characteristic adaptations that could be viewed as facets of extroversion, such as being passionate, communicative or self-confident, all of which are helpful in DUI mode innovation processes. Nevertheless, this does not mean that CEOs of innovative SMEs have to display a creative cognitive style all the time. While Marcati

et al. (2008) and Gelade (2002) connected the Big Five personality traits to Kirton's (1976) idea of adaptive and innovative cognitive styles, our qualitative analysis found characteristic adaptations that influenced DUI mode innovation in SMEs. Our results are, to a great extent, in line with the quantitative results of Papadakis und Bourantas (1998), Edmondson (1999) and Peterson et al. (2003) although their studies were based on different approaches. Hence, we conclude that the CEO of an innovative SME indeed has to be open-minded, but they do not have to be an 'Innovator', in the sense of Kirton (1976).

In using this qualitative approach, we have been able to explain *why* specific characteristics are important for successful DUI mode innovation processes. We found evidence that the CEO does not have to be an innovative person, but that openness to (external) ideas is crucial. At the same time, they have to exhibit an economical and efficient style of thinking, thus providing a basis for the 'real' innovators. According to the innovation-mode literature and our study, innovative ideas are mostly generated by employees, customers or other interaction partners, such as suppliers or consultants. We extracted from the interviews that the CEO mostly moderates and mediates a firm's internal learning-by-doing activities. According to Kirton's (1976) definition of individuals relying on an adaptive cognitive style, we hypothesise that top-executives of innovative SMEs would score lower on the KAI than some of their (innovative) employees. However, Kirton (1976) himself considered that the distance between individuals on this linear scale should not be greater than 20 points, otherwise, communication problems can occur. Foxall und Hackett (1994) emphasised that adaptors and innovators do not easily collaborate with each other. Thus, a 'facilitator', with a mid-range KAI, is needed, one capable of brokering between both cognitive styles. These facilitators, such as CEOs, are able to establish effective teams by striking a balance between problem-solvers and allowing for different cognitive styles. They concluded that, especially in times of uncertainty, most organizations depend on both cognitive styles.

This hypothesis is also in line with our findings on the characteristic adaptations that can be placed in the broad field of soft skills. For example, the qualitative analysis showed that characteristics that refer to higher social competencies, such as being cooperative and communicative, are connected to an integrative understanding of employee knowledge and a value-based relationship. This is directly linked to firm-internal learning-by-doing

activities, which seem to occur more easily in trustful environments. Cooperation with employees, customers and other firms were recognized as being core aspects of DUI mode innovation processes. Thus, the importance of those characteristics is highlighted because a decision-maker's social competencies have a positive effect on the level of employee absenteeism, satisfaction and motivation, as well as on customer satisfaction, their willingness to provide feedback and a reduction in price sensitivity (Hammann et al., 2009), all of which determine DUI mode innovation processes. Our findings are in line with of whose Peterson et al. (2003), who demonstrated significant correlations between higher levels of agreeableness, team cohesiveness and the decentralization of power and, thus, income growth.

In addition, we heard in the interviews that a thorough CEO was helpful in thinking holistically and allocating adequate resources for innovation projects. This characteristic was often mentioned together with the capability to play with ideas and being receptive to learning. These methodological skills have been contextually connected with team innovation activities, such as creative brain-storming. Peterson et al. (2003) also found a positive correlation between conscientiousness and team flexibility, as well as cohesiveness, both being positively correlated with income growth. As knowledge-sharing in SMEs occurs through cross-functionality and overlapping roles, and is facilitated by close proximity, the CEO also influences knowledge management (Wee & Chua, 2013), which is especially important in non-R&D-based SMEs due to its informal nature.

Our results also showed the interdependence of characteristics, as well as their connection to concrete behaviors, thus highlighting the complexity of a CEO's influence on DUI mode learning processes. Obschonka und Stuetzer (2017) reported a significant connection between an intra-entrepreneurial constellation of personality traits, which has also been connected, on a regional level, to higher entrepreneurship rates and innovation activities (Fritsch et al., 2019). However, this connection becomes insignificant when controlling for regional variables. Indeed, Fritsch et al. (2019) used patent data and R&D employment rates as proxies for innovation activities, which contradicts the definition of 'innovation', as perceived by entrepreneurs; that is, incremental improvements in existing organizational processes, products and structures (Marcati et al.). Because many entrepreneurial firms, often by intention, stay small (Hesse & Sternberg, 2017), we might assume that the effect between personality traits and innovation activities would be

greater, if the latter were measured in a more convincing way for most of the SMEs; that is, in a more DUI-orientated way.

This analysis not only improves our theoretical knowledge of innovation processes in SMEs, it also has implications for the measurement of innovations that are based on DUI mode learning. Although items for measuring personality traits, such as the Big Five or KAI, exist, we would not recommend a CEO's personality as being indicative of innovativeness in SMEs, per se. Due to the great complexity of CEO characteristics and DUI mode innovation activities, we would rather promote items that cover the innovation culture of a specific firm. The advantage of this is that one cannot directly control who is answering an online survey (the CEO, one of the secretaries or an assigned employee), whilst items covering innovation culture can be answered by any member of a firm. Indeed, in innovation survey, we could find only rather vague items that tried to cover the innovation culture experienced in innovative SMEs, through analyzing Germany's Mannheim Innovation Panel since 1993. This large-scale, annual innovation survey is Germany's contribution to the European Commission's Community Innovation Survey.

The practical implications of our study are given for the benefit of both business executives and regional innovation policies. One important insight might be that employees from all levels in the hierarchy should be invited to air their innovative ideas, even threshold workers and students (Alhusen & Bennat, 2020). This is deeply connected to the trustful atmosphere and innovation culture a CEO mediates. Thus, policy and business executives should be aware of this specific role. However, the CEO is not solely responsible for innovation activities in SMEs. In line with Andries und Czarnitzki (2014), non-managerial ideas are more important for innovation activities. Also, the CEO moderates innovation decisions, thus acting as a powerful gatekeeper to innovation activities in DUI mode SMEs. Actually, their direct influence decreases in the case self-governing project teams are constituted. Nevertheless, their indirect influence on innovation culture does not decrease at the same time.

Hence, the direct and indirect effects of CEO characteristics are deeply connected to DUI mode learning processes. For SMEs in particular, the CEO influences the employees' motivation to state their ideas and the possibility of developing or implementing innovations. These processes are crucial for DUI mode innovation output because, in many SMEs, there is no defined department for innovation and research. Thus, DUI mode innovations are rather developed alongside the daily business. However, this also explains

why we found less information about how top-executives influence a firm's innovation strategy, as theoretically expected by the upper-echelon model. Formal strategy papers are less applicable, even being redundant, in the informal learning and innovation setting of a non-R&D-based SME. More importance is given to engendering close proximity between the top-executive and the employees, connecting in a trustful atmosphere, with an innovation-friendly mindset.

We suggest a regional innovation policy that concentrates on the modifiable characteristic applications of top-executives, such as values, self-image or awareness of innovative ideas from others, including employees, customers or other interacting partners, as a way of fostering innovation activities in non-R&D-based SMEs. Evaluations of entrepreneurship workshops, targeted at improving specific personality traits, have shown fewer effects (Obschonka & Stuetzer, 2017). Thus, innovation policy must consider that innovation performance is not solely connected with managerial skills; it is also shaped by one's attitude. For example, attitude can be fostered by promoting the CEOs of innovative SMEs as role models, in order to inspire other top-executives to adjust their mindsets.

5.6 Conclusions

In the last few decades, research has shown that CEOs influence firm performance. These studies have often been based on greater medium-sized or large firms, and have indicated a quantitative connection between personality variables and performance output. However, in SMEs, the influence of the CEO seems to extend further, as they often have a personal relationship to the organization, and enjoy greater freedom in their decision-making and individual responsibilities (Hammann et al., 2009; Papadakis & Bourantas, 1998). SMEs differ from larger companies in many aspects, especially in the way they produce innovation. Following the innovation-mode concept, non-R&D-based SMEs substitute their potential disadvantage in not having formal innovation departments with different learning processes that are based on employee knowledge, customer integration or interaction with other stakeholders — the so-called DUI mode (Jensen et al., 2007). The influence of the CEO on DUI mode innovation activities has not previously been considered. However, due to the learning mechanism involved in DUI mode SMEs, the influence of the CEO seems to be even greater in those settings. Whilst larger companies

are organizationally designed for innovation processes, non-R&D-based SMEs are restricted to the voluntary contributions of their employees, in terms of innovation processes. Hence, the impact of the CEO on the employees seems to be more critical in DUI mode SMEs. In this paper, we answered the research question about how, and through which characteristics, the CEO influences DUI mode innovation in SMEs by analyzing 77 qualitative interviews of SME representatives and innovation consultants in Germany.

The main findings are, that the CEO influences DUI mode innovation processes directly by pursuing innovative ideas or rejecting opportunities through strategic choice-making. However, not only the strategies, but also the informal innovation culture, of a firm are shaped by CEO characteristics, which have a great impact on the SME's innovation output. A CEO's attitude, basic tendencies and soft skills also indirectly mediate the mechanism of DUI mode learning processes by influencing the informal innovation culture of an SME. Further, there is a high interdependence of CEO characteristics and their connection to the concrete mechanism of DUI mode learning processes. This indicates the great complexity of a CEO's influence on non-R&D-based SME innovation output.

There were some limitations to our study. We highlighted the importance of employee integration and motivation, in terms of DUI innovation processes, and how the CEO directly and indirectly affects these processes. Indeed, we did not integrate employees into our sample to understand their opinions about the influence of the CEO. Nevertheless, this weakness was minimized because we did not directly ask the CEOs about this topic, and we enhanced the analysis by using the general views of regional innovation consultants. Further, due to the qualitative method of this analysis, we were not able to generalize our findings in any statistical way. Rather, we improved the DUI-mode concept with insights from the business management literature, and were able to explain in some depth how, and through using which characteristics, CEOs influence DUI mode innovation processes. This connection must be tested quantitatively, in order for it to be reliable for a larger population of firms. However, such a quantitative approach will need more applicable indicators to measure the DUI mode innovation activities. As traditional indicators, such as patent data or R&D investment, do not represent innovation processes in non-R&D-based SMEs, future research should focus on the measurement variables. Additionally, further research is needed on the regional differences in CEOs'

influences on DUI mode activities. For example, Fritsch et al. (2019) observed different regional personality patterns, which were connected to different entrepreneurship rates. As we did not differentiate between our three sample regions, it remains unclear if there are further regional aspects to be revealed that could influence DUI mode innovation activities in innovative SMEs.

6 General Conclusions and Policy Implications

The overall aim of this dissertation was to shed light on the question how innovation processes in SMEs are organized and how regional innovation policy in Germany might adjust their strategies and offers to better support innovation activities at their specific region. In response to the first research question (What hinders combinatorial knowledge dynamics?), the first article of this dissertation showed that there are several barriers that hamper the exchange of analytical, synthetical, and symbolic knowledge. Contrary to the assumptions of the proponents of evolutionary economic geography - that actors prefer to interact with local partners, who have a similar knowledge base (high cognitive proximity) and share institutional, social, and organizational proximity (Boschma, 2018; Ponds et al., 2007) - our empirical results highlighted that this preference is only one of the factors that explain reduced combinatorial knowledge dynamics. Through analyzing the interviews, we identified a number of practical factors that exist alongside organizational barriers and cognitive distance, including inadequate funding, insufficient knowledge about the correct contact partner, and psychological barriers such as varying levels of motivation and feelings of inferiority in comparison with university professors. Further, barriers to combinatorial knowledge dynamics are strongly interrelated, implicating a shift in policy instruments from markedly monetary and STI-based to integrating cultural and creative economy and their specific ways of innovating. However, this shift is only partly visible in our findings, as political support for innovation was rather silo-like: on one hand it tends to connect analytical and synthetic knowledge and on the other hand it fosters innovation in symbolic knowledge on its own. The preceding analysis of the regional specialization in knowledge bases qualifies every region as having innovation potential, as long as policy support considers the unique needs and peculiarities of individual knowledge bases and thus innovation modes. However, it is important to note that not every single barrier we identified can be eliminated by regional-level action. In particular, politically sourced financial support is often regimented by national authorities. Thus, a transformation of innovation support is needed at all levels of policymaking.

Nevertheless, the qualitative approach of this dissertation allowed us to be open to all kinds of innovation processes, be they of STI or DUI mode. During empirical research, it became apparent that despite testifying several barriers between different knowledge

bases, most firms try, at least, to combine processes that we categorized as either STI or DUI. Knowing from previous research that this combination could be challenging to firms, we were interested in the concrete mechanisms by which combinatorial innovation modes are practiced (please see the second research question: Which mechanisms are used to integrate STI processes into DUI-mode learning routines?). Content analysis of interviews in the second article revealed that firms used several mechanisms to integrate STI practices into DUI-mode routines. Firms highlighted learning-by-STI through the reading of scientific journals or trade magazines, the use of the vocational education and training System (VET system), and the integration of external staff and academics, as well as R&D cooperation. However, as the level of complexity of the mechanisms derived rose, so too did the needed capacity, cost, and (thus) needed support. This finding poses significant policy implications, as a deeper focus on STI in innovation policy (Cooke, 2014) could neglect the needs of firms who rely on DUI-mode processes or combine low levels of STI and DUI modes. Thus, policy exceed the boundaries of the trend of technology-transfer activities and continuous improvement of R&D infrastructure, which only partly cover the mechanisms of combinatorial innovation modes. Our analysis highlights instead the importance of the VET system, which is coming to a partial end in Germany, and informal knowledge exchange between employees with different academic backgrounds. Further, the second article also evokes theoretical consequences as the STI and DUI modes were hardly found in sampled firms. Thus, we conclude that this dual differentiation of ideal modes is best understand in practice as a continuum of processes. This continuum can also help practitioners to categorize firms without pigeonholing them, rejecting their potential for combinatorial innovation.

The third article lends additional support to this policy implication. In addressing how and why SMEs become highly innovative (please see research question three: What configuration of learning mechanisms leads to high innovativeness?), I demonstrated that it is not only learning-by-science, nor its combination with DUI-mode processes, that sufficiently explains high innovativeness in the sampled SMEs. There was no evidence that the combination of learning-by-STI and learning-by-doing, -using and -interacting led to high innovation performance. In other words, it is not that "more of every mechanism" is promising high innovation performance. Rather, parts of DUI together with learning-by-science, as well as DUI alone, were sufficient conditions to achieve high innovativeness in our sample. However, no learning mechanism was identified as a

necessary condition. This suggests that firms focusing on their strengths, and thus on specific configurations of learning mechanisms, can find their own "recipes" for becoming highly innovative. This finding also reduces the risk of implementing putative "best practices" that do not fit a firm's setting. Furthermore, it has implications for regional innovation policies in search of instruments by which to foster innovation activities in SMEs, as innovation need not always entail the transfer of knowledge between research institutions and applying firms, as is suggested by the RIS approach (Asheim et al., 2016). Rather, firm-internal exchange, structures fostering employee integration in innovation processes, and exchange with customers, suppliers, and consultants are equally sufficient to explain high innovativeness. Yet it is not just the existence of these processes that is important for innovation performance; it is their implementation and their utilization of a firm's agents. Thus, the presence of a learning mechanisms enables firms to react in a specific fashion, but this fashion is determined by the willingness and ability to innovate of a firm's personnel. In summary, there exist different "recipes" for becoming highly innovative, but contrary to what some might expect, merely performing research is not one of them. Innovative output is strongly connected to the ability and willingness of a firm's agents to implement these mechanisms. This finding prioritizes the human side of successful innovation processes.

This was expanded upon in the fourth article, which answered the fourth research question (How do CEOs influence innovation processes in SMEs?). Analysing which personal characteristics of top executives influence innovation performance in non-R&D-based SMEs, it was discussed how innovative the CEO of such a firm must be if employee knowledge, customer ideas, and suppliers are at the core of their DUI-mode innovation processes. Results indicate that the CEOs need not be innovative themselves; rather, their ability to foster employee integration and interaction is critical to DUI-mode innovation. CEOs' individual characteristics moderate and mediate DUI processes and have effects on levels of employee absenteeism, satisfaction, and motivation, customer satisfaction and willingness to provide feedback, and price sensitivity (Hammann et al., 2009). In return, these micro-processes form the basis of DUI-mode innovation. Thus, the CEO is both directly and indirectly connected to DUI-mode learning processes, influencing employees' motivation to advance their ideas and the possibility of developing or implementing innovations. In light of the fact that many DUI-mode-learning SMEs do not maintain formal R&D structures, these effects become particularly important. This is

also in line with my findings on CEO influence on strategic choices, as was suggested by the upper-echelon approach (Hambrick & Mason, 1984). Formal strategic manifestations such as strategy papers become redundant in the informal learning-and-innovation setting of a non-R&D-based SME. Nevertheless, innovation consultants, funding applications, and innovation awards often focus solely on such manifestations, forcing firms into an "institutional corset" that does not fit their mode of innovating. Findings support focusing instead on creating close proximity between top executives and firm employees, generating an atmosphere characterized by trust in which an innovation-friendly mindset is favored.

In brief: SMEs' innovation activities rely strongly on their personnel - in particular, their informal understanding of knowledge exchange, low timidity when it comes to failure, and openness to interacting with customers, suppliers, or other firm-externals.

These acknowledgments lead to two main political consequences:

First, if the organization of learning processes and thus innovation activities in SMEs is less formal and strongly influenced by their experience of DUI mode mechanisms, than the political support of SMEs should be orientated at this nature of innovativeness.

Second, the traditional form of consultancy becomes more and more ineffective, as consultants are not part of the internal firm-learning processes. However, the firm-internals are the experts of a specific challenge. Thus, consultancy is facing a transformation from a deliberate expert towards a coach on eye-level, empowering firm-internals to find their own solutions. Thus, the role of consultancy is changing from a process-predeterminer towards a process-companion. This new understanding was mostly internalized by private innovation consultancies giving room for several public innovation consultancies to walk the talk as well.

6.1 Limitations and Further Research

Due to the exploratory nature of these studies, a few limitations must be considered, prompting further research. The use of a case-level design precluded us from transferring our results to a larger population or generalizing our findings. A quantitative approach - one which included the detailed information derived from the interviews - would be necessary to make generalization possible. The insights provided by this dissertation

should be used to measure innovation activities in SMEs in a more appreciable way. If SME's innovativeness were to become more visible to policy makers, it could lead to greater acknowledgement of their contributions to economic development. However, I also observed a shift in innovation policy. For example, the measurement of innovation output was recently redefined by some innovation panels (see, e.g., "KFW Innovationsbericht" (Zimmermann, 2020)). Nevertheless, most of the studied firms would not describe themselves as innovative, despite creating daily what researchers would view as innovations. This mismatch between the researcher's definition of innovation and the lived understanding of innovativeness in SMEs has consequences for further research: focusing on innovation output variables, like the number of product- or process-innovations, would wildly miss the mark of real innovation output, because many SMEs would not describe their innovations as innovation. Furthermore, incremental innovations in particular, which are often applied firm-internally, can be the basis of subsequent disruptive innovations. It would be a grave error to neglect their importance to economic growth and development. This gap should be recognized in further (quantitative) research on innovation in SMEs. We overcame this limitation by asking interviewees only about "alterations" (in German: *Neuerungen*), which was very helpful in collecting information about incremental innovations in addition to substantial leaps. The categorization of described alterations as innovations was made by the researchers in retrospect. On the other hand, the words "innovation" or "being innovative" have increasingly become the buzzwords of the last century - as can be observed on firms' websites or social-media marketing activities, for instance, which also has consequences for big data analysis that relies on tools like web scraping.

From an economic geography perspective, limitations are also inherent in the regional sampling of firms. Because the sample only covered regions which already enjoyed functional regional innovation systems and core cities filled with applicable firms, research institutions, and policy support, it is important to analyze whether innovation processes differ in rural areas. While some processes (like some barriers) seem to be quite similar across the studied regions, other topics differ in the details. One example is the understanding and use of the cluster strategy. While this term commonly appeared in interviews of both firms and regional consultancies in East-Thuringia, it was mentioned far less often by both sample groups in Hanover and Goettingen. This can be partly explained by historically developed structures of economy and the political support of

clusters in East-Thuringia. However, there were also cluster strategies for Hanover in the early 2000 as well (Sternberg, Kiesel & Schätzl, 2004), but they did not influence the "reality of innovation activities" from the interviewees at this region today. Therefore, regional policymakers should be very cautious about copying successful strategies, such as best practices, into other regions without having analyzed the existing regional frameworks (see Tödtling & Trippl, 2005). Further, in line with an evolutionary approach (Boschma, 2018), a region's specialization, barriers, and agents may vary over time. This has significant implications for both the region's image and the support needed there. Indications for that there especially found in Goettingen.

Further, aspects of digitalization and its influence on geographical proximity might be a promising research question. This is especially true for firms with digital business models or those in the creative sector. Considering the knowledge base approach and the innovation mode concept, it remains unclear whether a third innovation mode is needed for creative firms, which rely strongly on symbolic knowledge. Analytical knowledge is an aspect of the STI mode, and synthetic knowledge is referred to as a DUI mode - but which logic is required to use symbolic knowledge for innovation processes?

6.2 Prospects

Looking beyond the horizon of this dissertation, digitalization and globalization forebode a transformation of Germany's economy. In light of highly complex and global problems such as climate change and an aging population, innovation is becoming more important than ever. The economic effects of the COVID-19 pandemic have made it clear that innovation will be strongly connected with the ability to effectively collaborate in teams and with organizations to find creative solutions. However, innovation methods like design thinking, lean startup, and crowdsourcing will be fruitless until people are given a platform from which to spread their ideas (Raitner, 2019). Thus, managing and enabling knowledge workers is and will remain the core of innovation processes during this transformation - regardless of firm size. Innovation moves economic transformation forward, but at the same time, this very development also transforms innovation processes. While the linear model of innovativeness perfectly describes innovation procedures of the industrial age, the feedback model becomes increasingly important in knowledge economy. Even this concept, however, only partly addresses the rising

complexity of, and integration of different actors into, innovation processes. While the requirement of innovation was enhanced productivity in the 20th century (Drucker, 1999), some might recognize a modern shift towards social and ecological goals. However, to achieve these "new" goals, innovation processes might also change. As the human side of innovation is acknowledged: the empowerment of human potential will become take precedence over a conceptualization of employees as human resources. This is highly connected with the ability to self-manage, having great implications for organizational leadership. The task of leadership is changing from mere management of human resources to creating a culture where diversity and dissent can lead to more ideas. Simultaneously, conformity and consensus, as well as command and control, are losing momentum. Individuals and R&D departments will no longer be the sole core elements of innovation processes as the importance of *all* workers' ideas becomes recognized. Internal collaboration in decentralized teams leads to greater flexibility and faster processes (Raitner, 2019) - both important qualities when it comes to reacting to and transforming under rapidly changing conditions.

This does not, however, mean that leadership will lose its import. Rather, the role of leadership is changing from managing subordinates to leading associates to achieve sensible goals and collective visions. This will necessitate, however, a high level of trust and courage. If organizations' structures change from leader–follower to leader–leader (Marquet, 2012), and trust and courage are at the core of innovativeness (Raitner, 2019), what does this mean for our understanding of innovation processes and how we try to uncover them? What does this mean for innovation consultancy and policy?

Some findings hint that regional innovation consultancies and firms evaluate innovation processes in different fashions. In particular, the discrepancy between consultancies' advising innovation processes but continuing to work in old-fashioned public institutions seems to reduce, at least in part, firms' enrichment. It could be valuable to research how public consultancies could engage in innovation processes to enhance their own understanding of innovation, and thus their image at the firm level - especially as this dissertation highlighted that regional innovation policy could facilitate innovation processes in SMEs.

Finally, this also poses consequences for academic education. As innovation processes, the needs of consultancies, and the economy change, academia is confronted with

transformation as well. It remains to be seen whether traditional consulting and academic education will generally evolve the willingness and ability to develop.

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List of interviews

Regional Innovation Consultants

Number	Organization	Region	Interview length (minutes)	Date (yyyy-mm-dd)
C1	Public	Goettingen	75	2018-02-06
C2	Public	Goettingen	74	2018-03-21
C3	Privat	Goettingen	77	2018-05-30
C4	Privat	Goettingen	93	2018-02-08
C5	Privat	Goettingen	68	2018-07-08
C6	Privat	Goettingen	143	2018-07-19
C7	Public	Goettingen	71	2018-06-20
C8	Privat	Goettingen	88	2018-06-11
C9	Public	Goettingen	94	2018-06-27
C10	Public	Goettingen	84	2018-06-22
C11	Public	Hanover	72	2018-02-20
C12	Public	Hanover	73	2018-01-23
C13	Public	Hanover	91	2018-03-05
C14	Public	Hanover	55	2018-02-26
C15	Privat	Hanover	80	2018-02-26
C16	Public	Hanover	77	2018-05-29
C17	Privat	Hanover	80	2018-05-28
C18	Public	Hanover	69	2018-06-01
C19	Privat	Hanover	66	2018-06-19
C20	Public	Hanover	65	2018-06-28
C21	Public	Hanover	54	2018-06-18
C22	Public	Hanover	n/a no permission to record interview	2018-07-23
C23	Public	Jena	91	2018-06-20
C24	Public	Jena	49	2018-06-26
C25	Public	Jena	85	2018-06-27
C26	Public	Jena	40	2018-07-04
C27	Public	Jena	66	2018-07-17
C28	Public	Jena	57	2018-07-19
C29	Privat	Jena	62	2018-08-20
C30	Public	Jena	81	2018-08-17
C31	Privat	Jena	73	2018-08-13
C32	Public	Goettingen	60	2018-09-06

Small and mediums sized enterprises

No.	Position of interviewee	Region	length (min.)	NACE Code	Date (yyyy-mm-dd)
Mainly DUI					
F 5	CEO	Goettingen	73	CA - Manufacture of food products, beverages and tobacco products	2018-07-18
F 17	CEO	Hanover	60	S - Other service activities	2018-05-03
F 19	CEO	Hanover	64	M - Professional, scientific and technical activities	2018-07-02
F 33	CEO	Hanover	74	G - Wholesale and retail trade; repair of motor vehicles and mo	2018-09-27
F 39	CEO	Jena	39	CI - Manufacture of computer, electronic and optical products	2018-10-12
F 41	CEO	Jena	17	CH - Manufacture of basic metals and fabricated metal products,	2018-10-15
F 43	CEO	Jena	26	G - Wholesale and retail trade; repair of motor vehicles and mo	2018-10-23
F 48	CEO	Jena	89	CI - Manufacture of computer, electronic and optical products	2018-02-22
DUI and STI					
F1	CEO	Goettingen	104	M - Professional, scientific and technical activities	2018-06-14
F2	CEO	Goettingen	66	B - Mining and quarrying	2018-07-05
F 3	Executive	Goettingen	71	F - Construction	2018-07-10
F 6	CEO	Goettingen	67	CM - Other manufacturing, and repair and installation of machin	2018-07-20
F 7	Executive	Goettingen	64	CA - Manufacture of food products, beverages and tobacco produc	2018-08-08
F 9	CEO	Goettingen	76	J - Information and communication	2018-08-16
F 10	CEO	Goettingen	63	G - Wholesale and retail trade; repair of motor vehicles and mo	2018-08-16
F 11	Executive	Goettingen	40	CH - Manufacture of basic metals and fabricated metal products,	2018-08-17
F 13	CEO	Goettingen	78	G - Wholesale and retail trade; repair of motor vehicles and mo	2018-08-21
F 16	CEO	Goettingen	84	CI - Manufacture of computer, electronic and optical products	2018-09-05
F 18	Development	Hanover	70	F - Construction	2018-06-08

F 20	CEO	Hanover	55	J - Information and communication	2018-07-04
F 21	CEO	Hanover	70	J - Information and communication	2018-07-05
F 22	CEO	Hanover	33	Q - Human health and social work activities	2018-07-05
F 24	CEO	Hanover	64	CH - Manufacture of basic metals and fabricated metal products,	2018-07-23
F 27	CEO	Hanover	40	A - Agriculture, forestry and fishing	2018-09-03
F 28	CEO	Jena	92	CI - Manufacture of computer, electronic and optical products	2018-07-25
F 29	CEO	Hanover	87	CK - Manufacture of machinery and equipment n.e.c.	2018-09-12
F 30	CEO	Goetting en	58	M - Professional, scientific and technical activities	2018-09-11
F 35	CEO	Jena	67	N - Administrative and support service activities	2018-09-11
F 37	CEO	Goetting en	75	CI - Manufacture of computer, electronic and optical products	2018-10-08
F 38	CEO	Jena	29	CI - Manufacture of computer, electronic and optical products	2018-10-10
F 40	CEO	Jena	35	CI - Manufacture of computer, electronic and optical products	2018-10-15
F 42	CEO	Jena	89	CA - Manufacture of food products, beverages and tobacco produc	2018-10-17
F 44	CEO	Jena	49	CH - Manufacture of basic metals and fabricated metal products,	2018-10-23
F 45	CEO	Jena	32	CH - Manufacture of basic metals and fabricated metal products,	2018-10-23
F 46	CEO	Jena	12	J - Information and communication	2018-10-24
F 47	Execu tive	Jena	70	CH - Manufacture of basic metals and fabricated metal products,	2018-10-30
Mainly STI					
F 4	CEO	Goetting en	96	J - Information and communication	2018-07-11
F 8	CEO	Goetting en	71	CI - Manufacture of computer, electronic and optical products	2018-08-10
F 12	CEO	Goetting en	64	CI - Manufacture of computer, electronic and optical products	2018-08-21
F 14	CEO	Goetting en	7	M - Professional, scientific and technical activities	2018-08-23
F 15	CEO	Goetting en	80	CI - Manufacture of computer, electronic and optical products	2018-08-27
F 23	CEO	Hanover	85	CE - Manufacture of chemicals and chemical products	2018-07-10

F 25	CEO	Hanover	44	CK - Manufacture of machinery and equipment n.e.c.	2018-08-28
F 26	CEO	Hanover	90	CK - Manufacture of machinery and equipment n.e.c.	2018-08-28
F 31	CEO	Hanover	42	CI - Manufacture of computer, electronic and optical products	2018-09-14
F 32	CEO	Hanover	66	J - Information and communication	2018-09-19
F 34	CEO	Jena	150	CI - Manufacture of computer, electronic and optical products	2018-09-06
F 36	CEO	Jena	31	CI - Manufacture of computer, electronic and optical products	2018-10-08
F 49	Executive	Jena	109	CI - Manufacture of computer, electronic and optical products	2018-03-28

Appendix

Annex I

Interview with firm representative:

- Please give us a brief description of your personal development and your position at the firm.
- Please describe to us some basic data of your firm.
- Please briefly explain your current market environment with regards to: main customers, the geographic range of your products as well as your competitive situation.
- What novelties did your firm – in a broad sense – produce?
- Do you conduct a systematic search for new (scientific) knowledge and methods?
- What kind of novelties or improvements occur as a result of the production of goods or services?
- What role does experience-based knowledge and employee's competencies play for novelties?
- How does knowledge and experience exchange take place at your firm, especially during the production of goods and services?
- How do customers influence novelties and improvements?
- How does exchange with customers take place?
- How do competitors influence novelties and improvements?
- How does exchange with competitors take place?
- What role do other external actors (banks, regional consultancies, etc.) play for novelties?
- How does exchange with other actors take place?
- Is digitization an important topic for your firm, what are its effects?
- Did competencies at your firm changed within the last 10 years? Did you had to unlearn knowledge?

Regional Innovation Consultancies

- What does your job description say about promoting innovation in SMEs? (short)
- How do you define innovation? How do your clients define innovation?
- How do SMEs innovate without formal R&D? What processes in SMEs foster innovation?
- Which particular factors favor the capability to innovate in SMEs in our region?
- How does cooperation with other firms or organizations influence innovation capabilities of SMEs?
- What role does experience-based knowledge play in SME's innovation processes?
- What role does different knowledge (for example from universities, other industries or the creative sector) play in SME's innovation processes?
- Are there regionally specific factors that influence the innovation capability of SMEs in our region?
- Which kind of challenges do you face for regional innovation policy to increase innovation activities in SMEs in our region?

Annex II

Matching of occupation groups and knowledge bases

The matching of occupation groups and knowledge bases was done through an analysis of the four-digit occupation subgroups and detailed job descriptions provided by the Federal Employment Agency in Germany (Federal Employment Agency Germany, 2017). We took out (three-digit) occupation groups with mixed knowledge bases in certain (four-digit) occupation subgroups (e.g. *233 Occupations in photography and photographic technology*, including: *2331 Occupations in photographic technology* which would be synthetic and *2332 Occupations in photography* which would be symbolic), as well as occupations that were not directly involved in product or process development (e.g. public administrator, schoolteacher, military). We did not exclude clerks or blue-collar workers because previous studies on DUI-mode innovation have shown that these groups also contribute to the innovation and knowledge generation process through mostly informal learning dynamics (Thomä, 2017, 2018).

Descriptive Statistics of location quotients

	Minimum	Maximum	Mean of LQs	Std.-deviation*	Class limits
LQ analytic	0.3626	3.1675	0.9261	0.3804	1.3804/ 0.6196
LQ synthetic	0.8335	1.0794	1.0133	0.0398	1.0398/ 0.9611
LQ symbolic	0.2235	3.6268	0.7931	0.4409	1.4409/ 0.5591
* was used to calculate thresholds of below- and above-average of 1 (as the theoretical point of equal concentration)					

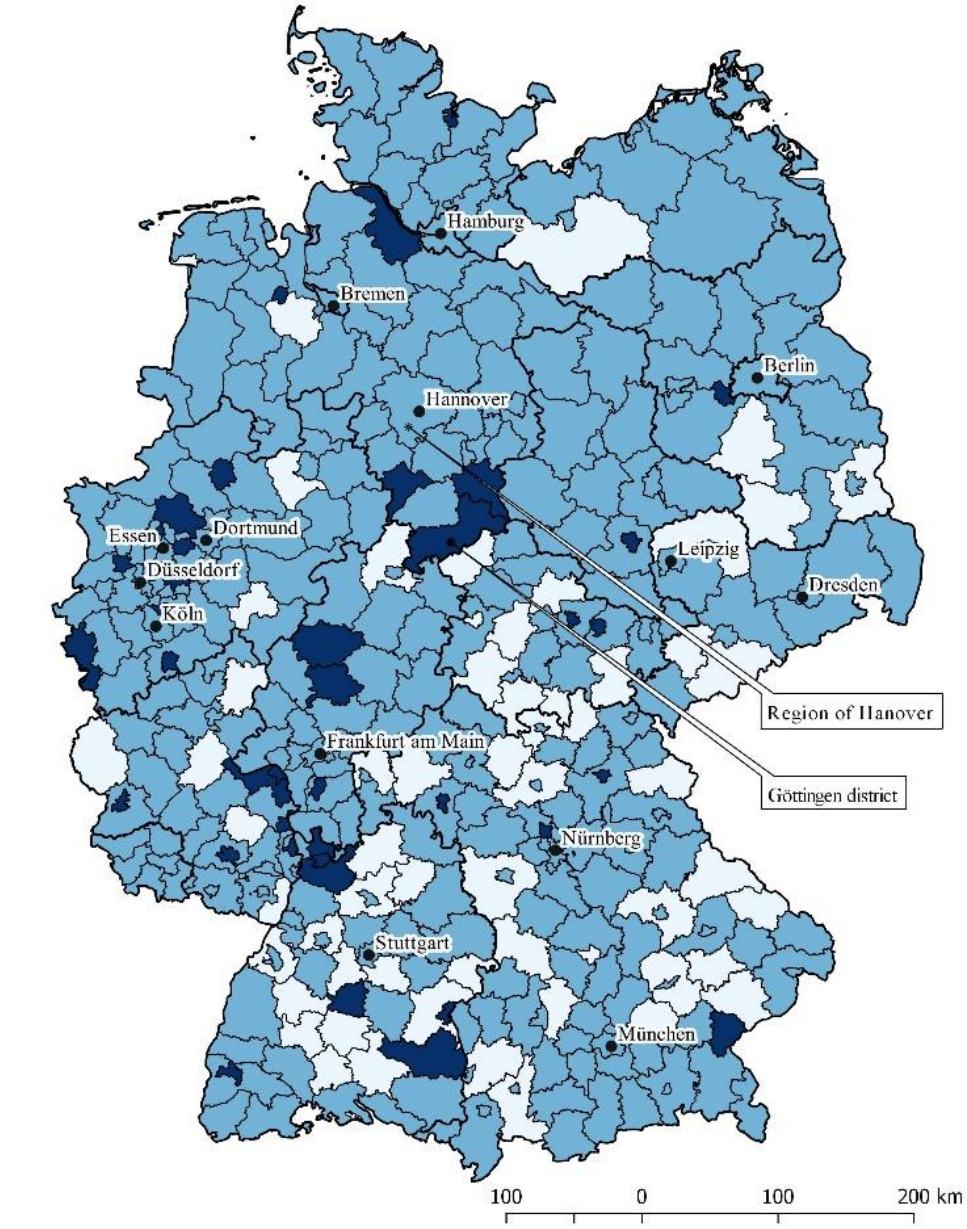
Geography of knowledge bases in German regions

The following maps present the geography of knowledge bases in German regions. Figure 1a displays the LQs for occupations attributed to the analytical knowledge base. The highest concentration of scientific knowledge can be found in the Altöttingen district (LQ = 3.17; see Appendix I for descriptive statistics of the LQs) and Heidelberg City (LQ = 2.91). The first is known as the chemical triangle of Bavaria, containing international high-tech firms and their suppliers (https://www.chemdelta-bavaria.de/). The second, Heidelberg, the ‘City of Science’, is the oldest university town in Germany; in 2012, the University of Heidelberg was again honored for being an elite university. Altogether, 37

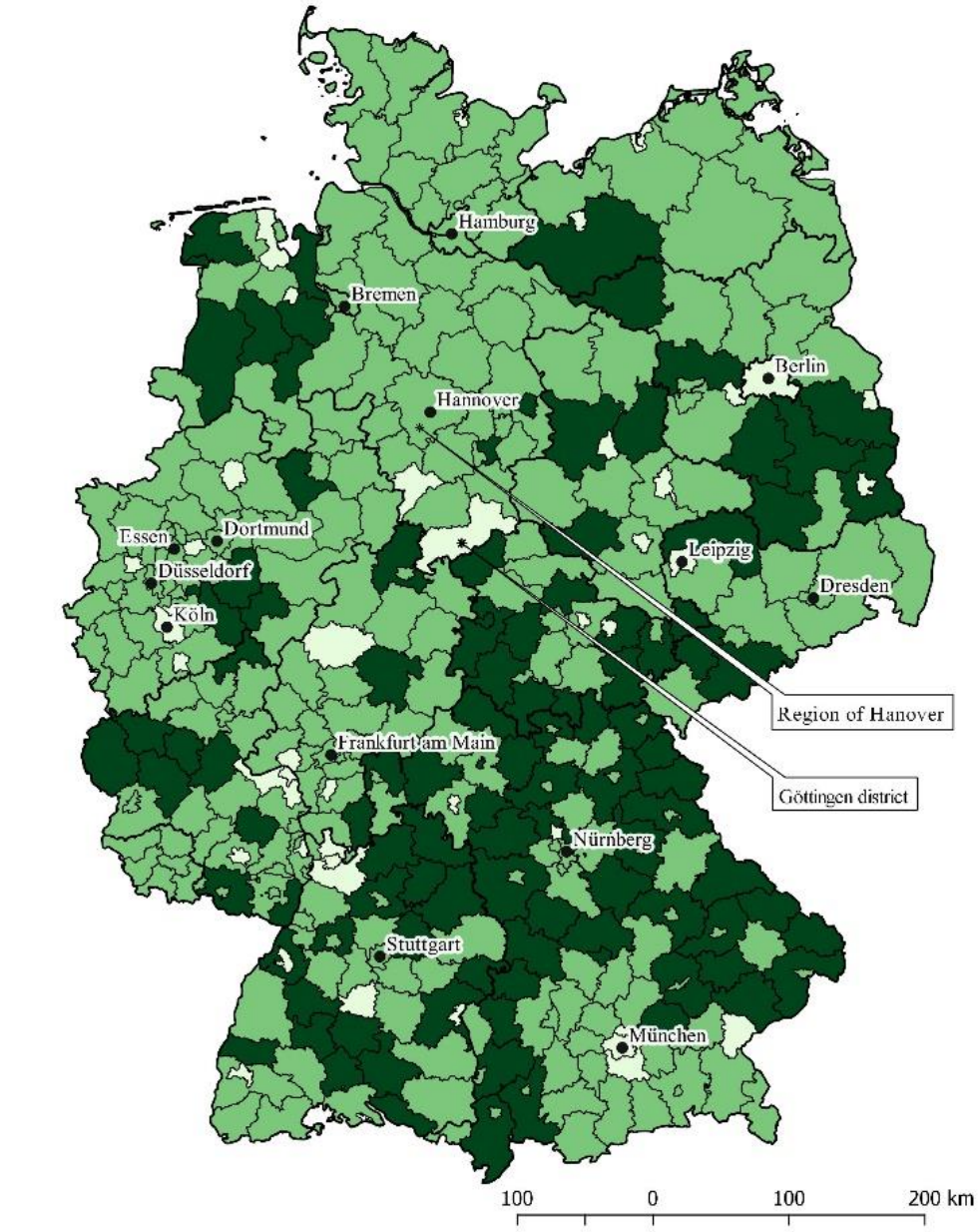
regions exhibited an above-average concentration of analytical knowledge base. Out of those, more than half (25) were independent towns. Indeed, none of them are located in districts containing major cities with more than 500 000 citizens. Hence, a concentration of analytical knowledge is more often represented in districts with medium-sized towns or smaller cities (smaller core-regions). This is in line with the findings of Eder (2018), showing that analytical knowledge cannot only be found in agglomerations, but also in peripheral areas. This is underpinned by a weak positive correlation between the LQs of analytical knowledge base and gross domestic product (GDP) per capita (0.23; see correlations in Table).

A similar correlation also exists between the symbolic knowledge base and the GDP per capita (0.25). As Figure 2a illustrates, almost all those districts with above-average LQs for the symbolic knowledge base are urban districts, i.e. dominated by one city. Nine of them are major cities with more than 500,000 citizens (core-regions). The highest LQ was found in Frankfurt (Oder) city (LQ = 3.63) and Schwerin city (LQ = 2.99). Both are job locations for a comparatively high number of workers in media and marketing, as well as journalism. In the case of the synthetic knowledge base, the map differs from the previous two (see Figure 3a) in that no major city is specialised in synthetic knowledge. This occurs more frequently in peripheral counties with medium-sized or smaller, towns. The highest LQ was measured in the Dingolfing-Landau (1.08) and Sömmerda (1.07) districts, which are known to be locations for the automotive, machinery construction and metalworking industries (https://www.landkreis-dingolfing-landau.de; http://www.landkreis-soemmerda.de). The synthetic LQs correlate weakly negative with the GDP per capita (-2.78) and strongly negative with the LQs of analytical (-0.93) and symbolic (-0.67) knowledge.

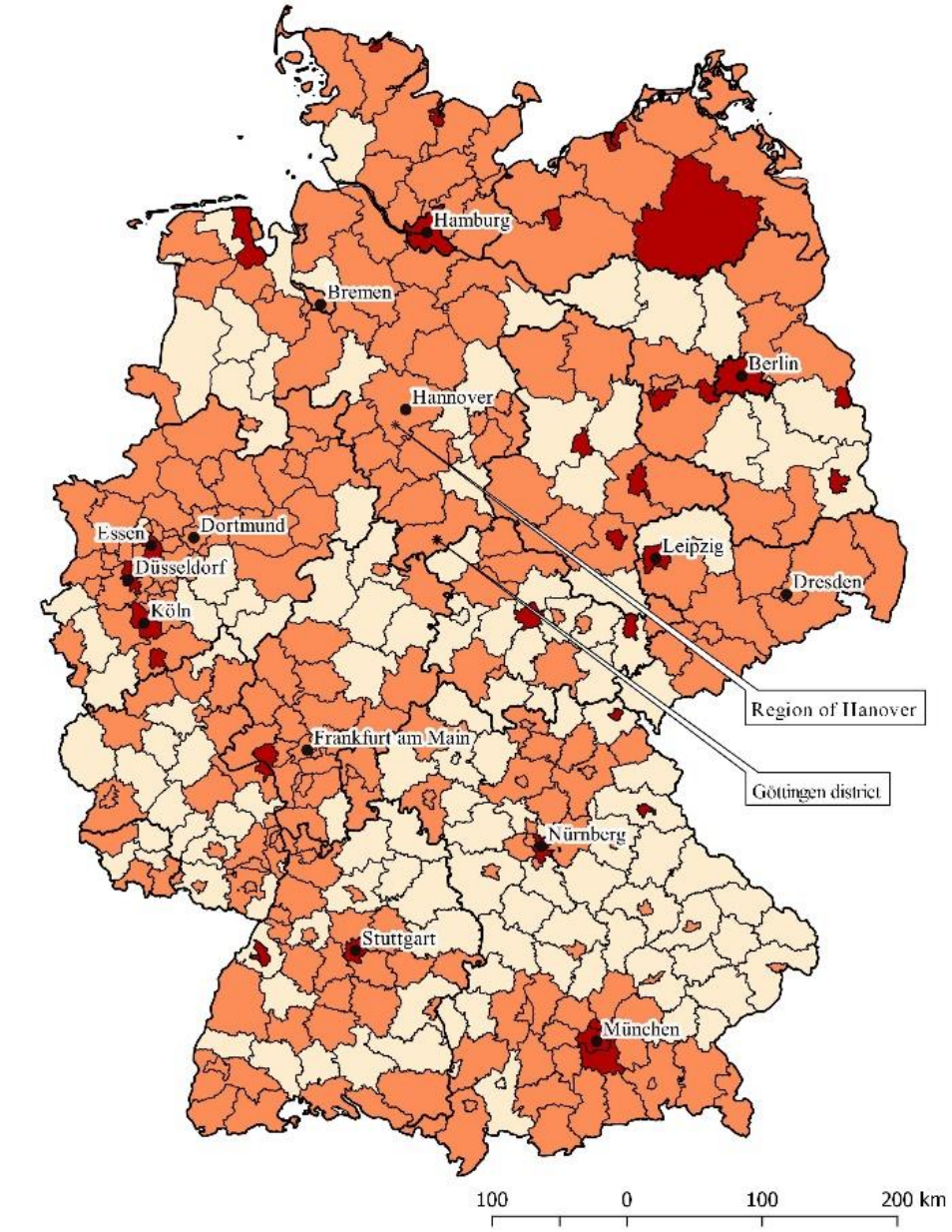
Geography of analytic knowledge base



Geography of synthetic knowledge base



Geography of symbolic knowledge base



Federal State boundaries
District boundaries

City

● > 500000 citizen

LQ Symbolic Knowledge Base

	< 0.559	[128]
	0.599-1.441	[242]
	> 1.441	[31]

Correlations

Correlation (Pearson)				
	GDP/capita 2016	LQ analytic	LQ synthetic	LQ symbolic
GDP/capita 2016	1			
LQ analytic	.228**	1		
LQ synthetic	-.278**	-.934**	1	
LQ symbolic	.253**	.365**	-.674**	1
**.Correlation is significant at the 0.01 level (2-tailed); N= 401				

Barriers of combinatorial knowledge dynamics

	synthetic	analytic	symbolic
Perception of potential for combinatorial knowledge dynamics		Universities do not exercise 3rd Mission; do not be aware of their regional role for skilled workers/ requires coverage of the firms; No creative study programs in Goettingen	Symbolic knowledge does not attract much political attention in Goettingen
Interest in different knowledge	surplus of orders keeping workers from innovation activities (especially craftsmen) support of thesis is time-consuming	Basic research without practical relevance; Students have no work experience; high employee fluctuation; Universities does not foster interdisciplinary knowledge exchange	Symbolic knowledge is less important for production; Assignment of externals for creative tasks; No Experience; No practical relevance; High costs→ dissatisfaction of costumers; co-working is inefficient; symbolic service provider submit even traditional solutions
Length of project time	To impatient; looking for quick results (competitive pressure); time length of projects (especially for start-ups); lack of time	Too rigid; to administrative; long decision-making processes; Applied Science professors are CEOs at once→ lack of time	traditional Business structure hampers creative exchange; Business-Units keep pushing themselves forward; Knowledge exchange is not fostered, lack of time
Outcome of combination	Do not recognize the benefit; after the cooperation need of knowledge and time for implementing the results, getting ready for the market, profitability; Have to implement the results by their own.	Knowledge Transfer sometimes not in dialog, no real collaboration;	Methods like Design thinking: Hype/ impendence of self-iconic (→ increases refusal); simple implementation of this methods do not work; Innovation culture not open for this methods (especially in old/traditional industries); creative processes are not easily implemented like manager wish to.

Interest in Publishing	Interested in confidentiality; overwhelmed with License negotiation;	Interested in License/ patents/ publications; Further use of the results in subsequent project, while the firms isn't involved anymore	No motivation to exchange creative knowledge out of fear for rip of ideas.
Psychological barriers	frightened by professors/ high level of knowledge, Uncertainty about priority of the project at University	„Kingdom-behavior" of many Professors,	CEO do not delegate authority; thinking in terms of hierarchy; low self-confidence for combining different knowledge
Finding the right contact person	Do not know the right contact person; prefer personal (sometimes trans-regional) contacts, although regional knowledge exists;	Universities don't know the right firm; TTOs are not able to ably to every request, too little financial resources; TTOs don't know about already existing cooperation; low TT in practice, just selecting contacts. Lower Saxony has no Research-Project-database.	office for economic development advises 'New Work' while working in traditional structures; Supporting creatives recently was added to the agenda; strategies of knowledge exchange outmoded; missing of a platform; TT and industry-networks do not involve creatives. Creatives do not plug into promotion
Financing	Overwhelmed with document duty; unmotivated because of low subsidy share; Have to cofund while universities get 100% financed. SMEs < 10 employees ZIM-Projects are refused	Institutes get just a small share of the recruited subsidies. Required budget of the universities too high for SMEs.	Too expensive

Annex III)

Matrix of calibration scores

Region	Case	Innovativeness	Doing	Using	Interacting	STI
East-Thuringia	F28	1	0,4	1	0,4	0,6
	F34	1	0,6	1	0,6	0,8
	F35	0,8	0,8	0,2	0,6	0,6
	F36	0,8	0,6	0,8	0,6	0,6
	F38	0,6	0,6	0,8	0	0,6
	F39	0,8	0,4	1	0,4	0,4
	F40	0,8	0,6	0,8	0,6	0,6
	F41	0	0,4	0,4	0	0
	F42	0,6	0,6	0,2	0,8	0
	F43	0	0,4	0,6	0,2	0
	F44	0,6	0,4	0,6	0,6	0,6
	F45	0,2	0,4	0,4	0,2	0,4
	F46	0,4	0,6	0,4	0,6	0,2
	F47	0,2	0,4	0,4	0,2	0,4
	F49	0,8	1	0,6	0,6	0,8
Hanover	F17	0,6	1	0,4	0,4	0,2
	F18	0,6	0,6	0,2	0,4	0,6
	F19	0,2	0,8	1	0,8	0,2
	F20	0,6	0,6	0,6	0,8	0,4
	F21	0,6	0,4	0,8	0,4	0,4
	F22	0,4	0,4	0,6	0,4	0,6
	F23	1	1	1	1	0,8
	F24	1	0,8	0,8	0,6	0,6
	F25	0,2	0,8	0,8	0,6	1
	F26	1	0,6	0,8	0,4	0,8
	F27	0,4	0,2	0,6	0,2	0,4
	F29	0,6	0,8	0,8	0,6	0,4
	F31	0,8	0,8	1	0,8	0,8
	F32	0,4	1	0,8	1	1
	F33	0,4	1	0,2	0,6	0,2

Goettingen	F1	1	0,8	0,8	0,2	0,6
	F2	0,6	0,8	1	0,4	0,4
	F3	0,8	0,6	0,6	0,6	0,2
	F4	0,6	0,6	0,4	0,6	0,4
	F5	0,4	0,6	0,2	0,4	0
	F6	0,6	0,8	0,8	0,2	0,6
	F7	0,6	0,8	0,8	0,6	0,6
	F8	0,8	1	1	0,8	0,8
	F9	0,2	0,6	0,2	0,6	0,2
	F10	0,8	0,8	0,6	0,6	0,4
	F11	0,6	0,4	0	0,8	0,6
	F12	0,8	1	0,6	0,6	0,8
	F14	0,2	0,4	0,6	0,4	0,6
	F15	0,6	0,4	0,6	0,6	1
	F16	0,8	1	1	0,6	0,6
	F30	0	0,2	0,4	0,2	0,6
	F37	1	0,2	0,6	0,4	0,6

fsqca-software outputs (full results)

```
Variable          Mean     Std. Dev.   Minimum    Maximum  N Cases  Missing
innovation    0.5914894    0.2857091         0          1       47        0
doing         0.6382979    0.2357001       0.2          1       47        0
using         0.6340426    0.2715414         0          1       47        0
interacting   0.5106383    0.2289979         0          1       47        0
sti           0.5106383    0.2603059         0          1       47        0


Analysis of Necessary Conditions
Outcome variable: innovation
Conditions tested:
              Consistency    Coverage
doing         0.834532       0.773333
using         0.834532       0.778524
interacting   0.733813       0.850000
sti           0.741007       0.858333
~doing        0.467626       0.764706
~using        0.438849       0.709302
~interacting  0.611511       0.739130


Analysis of Necessary Conditions
Outcome variable: ~innovation
Conditions tested:
              Consistency    Coverage
doing         0.791667       0.506667
using         0.739583       0.476510
interacting   0.687500       0.550000
sti           0.645833       0.516667
~doing        0.645833       0.729412
~using        0.656250       0.732558
~interacting  0.812500       0.678261

************************************************************
*TRUTH TABLE ANALYSIS: high innovativeness without assumptions*
************************************************************
Model: innovation = f(doing, using, interacting, sti)
Algorithm: Quine-McCluskey
for prime implicants: ~doing*interacting

--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 0.910448
Assumptions:
                             raw        unique
                            coverage    coverage   consistency
                           ----------  ----------  ----------
doing*sti                  0.676259    0.0791366   0.903846
interacting*sti            0.625899    0.0287769   0.925532
doing*using*interacting    0.633094    0.0719424   0.897959
solution coverage: 0.776978
solution consistency: 0.885246


**********************
*TRUTH TABLE ANALYSIS*
**********************
Model: innovation = f(doing, using, interacting, sti)
Algorithm: Quine-McCluskey
```

```
for prime implicants: interacting*sti

--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 0.910448
Assumptions:
                             raw       unique
                          coverage    coverage   consistency
                         ----------  ----------  ----------
doing*sti                0.676259    0.0791366   0.903846
interacting*sti          0.625899    0.0287769   0.925532
doing*using*interacting  0.633094    0.0719424   0.897959
solution coverage: 0.776978
solution consistency: 0.885246


************************************************************
*TRUTH TABLE ANALYSIS: high innovativeness with assumptions*
************************************************************
Model: innovation = f(doing, using, interacting, sti)
Algorithm: Quine-McCluskey

--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 0.910448
Assumptions:
doing (present)
using (present)
interacting (present)
sti (present)
                             raw       unique
                          coverage    coverage   consistency
                         ----------  ----------  ----------
doing*sti                0.676259    0.0791366   0.903846
interacting*sti          0.625899    0.0287769   0.925532
doing*using*interacting  0.633094    0.0719424   0.897959
solution coverage: 0.776978
solution consistency: 0.885246

****************************************************************
*TRUTH TABLE ANALYSIS average innovativeness without assumptions*
****************************************************************
Model: ~innovation = f(doing, using, interacting, sti)
Algorithm: Quine-McCluskey

--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 0.804348
Assumptions:
                           raw       unique
                        coverage    coverage   consistency
                       ----------  ----------  ----------
~using*~interacting    0.572917    0.03125     0.820896
doing*~using           0.583333    0.0416667   0.777778
~using*sti             0.447917    0           0.781818
solution coverage: 0.645833
solution consistency: 0.775


************************************
*TRUTH TABLE ANALYSIS of average innovativeness with assumptions*
```

```
************************************
Model: ~innovation = f(doing, using, interacting, sti)
Algorithm: Quine-McCluskey

--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 0.804348
Assumptions:
~doing (absent)
~using (absent)
~interacting (absent)
~sti (absent)
              raw       unique
            coverage    coverage   consistency
           ----------  ----------  ----------
~using     0.65625     0.65625     0.732558
solution coverage: 0.65625
solution consistency: 0.732558
```

The reduction of the truth table for average innovativeness reveals under the assumption it should contribute to average innovativeness than the cause is absent[14], that only ~using explains this outcome for all cases together. This term explains 65% of the memberships in the outcome and is consistent at the level of 0.73. In a nutshell, ~using is a sufficient condition for average innovativeness.

[14] Without assumptions, consistency rates are a bit higher, coverage is at the same level. However, solution terms would be in logical dissonance with the results for each region.

Co-author declarations

Institut für Wirtschafts- und Kulturgeographie

Leibniz Universität Hannover

Erklärung über die individuellen Anteile an der/m gemeinsamen Veröffentlichung/Manuskript (bitte Titel einfügen):

Knowledge bases in German regions: What hinders combinatorial knowledge dynamics and how regional innovation policies may help

zwischen Tatjana Bennat (Name DoktorandIn)

und Rolf Sternberg (Name Co-AutorIn)

Die wissenschaftliche Leistung[1] des Aufsatzes verteilt sich wie folgt:

Tatjana Bennat (Vorname, Name DoktorandIn):

- Idee und Konzept des Papers
- Datenerhebung, Aufbereitung und Analyse
- Ergebnisdarstellung und Diskussion
- Verschriftlichung
- Corresponding Author

Rolf Sternberg (Vorname, Name Co-AutorIn):

- Literaturarbeit
- Schärfung der Inhalte

Gemeinsam erstellte Teile:

- keine

Vor dem Hintergrund der oben geschilderten Arbeitsanteile bewerten die Unterzeichnenden den individuellen wissenschaftlichen Anteil an dem gemeinsamen Aufsatz einvernehmlich mit

80 % Tatjana Bennat und

20 % Rolf Sternberg

Datum, Ort: 06.08.2020 Hannover

(Siehe Originale für Unterschriften)

Unterschrift, Vorname, Name Doktorand/in

Unterschrift, Vorname, Name Ko-Autor/in

[1] z.B. Validierung und Schärfung von Inhalten, Ableitung von Implikationen, Non-Response Analyse, Forschungsdesign und -methodik, Datenerhebung, Konzeptionierung des Aufsatzes, theoretischer Bezugsrahmen, Literaturarbeit, empirische Analyse, Ergebnisaufbereitung und -darstellung, Ergebnisse und Diskussion, Verschriftlichung der Inhalte

Institut für Wirtschafts- und Kulturgeographie

Leibniz Universität Hannover

Erklärung über die individuellen Anteile an der/m gemeinsamen Veröffentlichung/Manuskript (bitte Titel einfügen):

Combinatorial innovation modes in SMEs: Mechanisms integrating STI processes into DUI mode learning and the role of regional innovation policy

zwischen Tatjana Bennat (Name DoktorandIn)

und Harm Alhusen (Name Co-AutorIn)

Die wissenschaftliche Leistung[1] des Aufsatzes verteilt sich wie folgt:

Tatjana Bennat (Vorname, Name DoktorandIn):

- Analyse der Interviews regionaler Akteure
- Verschriftlichung von Kapitel:
  - Theorie mit Fokus auf räumliche Aspekte
  - Methodik
  - Ergebnisse mit Fokus auf Barrieren
- Corresponding Author

Harm Alhusen (Vorname, Name Co-AutorIn):

- Analyse der Interviews von Unternehmen
- Verschriftlichung von Kapitel:
  - Theorie mit Fokus auf Kombinationen
  - Einleitung
  - Ergebnisse mit Fokus auf Mechanismen

Gemeinsam erstellte Teile:

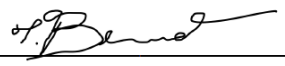
- Idee und Konzept des Papers
- Datenerhebung, Aufbereitung und Analyse
- Ergebnisdarstellung und Diskussion und Ableitung von Implikationen

Vor dem Hintergrund der oben geschilderten Arbeitsanteile bewerten die Unterzeichnenden den individuellen wissenschaftlichen Anteil an dem gemeinsamen Aufsatz einvernehmlich mit

50 % Tatjana Bennat und

50 % Harm Alhusen

Datum, Ort: 06.08.2020 Hannover



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Curriculum Vitae

Tatjana Bennat (*24th September 1991) is a research fellow at the Institute of Economic and Cultural Geography at Leibniz Universität Hannover. She received her higher education entrance qualification in 2011 from Schule am Kanstein, Salzhemmendorf-Germany. She completed a bachelor's and a master's degree from Leibniz University Hannover in Economic Geography and graduated 2017 as one of the best for which she was honoured by the alumni association WiGeoH. During her masters she spent a semester at Salford University, Manchester UK. She started her PhD in October 2017, which was founded by the German Federal Ministry of Education and Research under Grant 16IFI005. She was three semesters teaching statistics in bachelor courses and organised and guided excursions to Leipzig. Furthermore, she holds presentation at the following conferences:

- Bennat, T. (2020): How top-executives matter for DUI mode innovation: CEO characteristics and their influence on innovation activities in non-R&D-based SMEs. 5TH GEOGRAPHY OF INNOVATION CONFERENCE 2020, Stavanger, Norway, 29.01.2020.
- Bennat, T (2019): Knowledge bases in German regions: What hinders combinatorial knowledge dynamics and how regional innovation policies may help. 22nd Uddevalla Symposium 2019, L'Aquila (Italien), 27.6.2019.
- Bennat, T. (2019): Forschung zur besseren Innovationsmessung im deutschen Mittelstand. IIDEOS Kolloquium Kassel, 19.02.2019.
- Bennat, T. (2018): Zur Geographie von Wissensbasen in deutschen Regionen und der Rolle von Regionalpolitik. AK Industrie Geographie Naurod-Niedernhausen, 16.-17.11.2018.
- Bennat, T. (2018): Die Rolle von KMU in Regionalen Innovationssystemen. ifh-Beraterseminar „Region und Regionalität - Eine Chance für das Handwerk?“, Erfurt, 05.11.2018.
- Bennat, T. (2018): Exploratory evidence on the measurement of learning by doing-using-interacting. Jena Lecture Series in Economic Geography, Friedrich Schiller University Jena, 07.- 08.05.2018

To conclude, a complete list of her scientific publications (as of 08.09.2020):

- Bennat, T.; Sternberg, R. (2020): Knowledge bases in German regions: what hinders combinatorial knowledge dynamics and how regional innovation policies may help. European Planning Studies 28(2), 319-339. DOI: 10.1080/09654313.2019.1656168
- Alhusen, H. & Bennat, T. (2020). Combinatorial innovation modes in SMEs: mechanisms integrating STI processes into DUI mode learning and the role of regional innovation policy. European Planning Studies, 3(1), 1–27. https://doi.org/10.1080/09654313.2020.1786009
- Alhusen, H., Bennat, T., Bizer, K., Cantner, U., Kalthaus, M., Proeger, T. et al. (2019). The doing-using-interacting mode of innovation in SMEs: A novel measurement approach (ifh working papers, Hrsg.) (23). Göttingen. (not part of this dissertation)
- Bennat, T.; Broekel, T.; Sternberg, R. (2019): Zur Messung der Nutzung regionaler Potenziale beim Ausbau erneuerbarer Energien. Eine empirische Analyse deutscher Landkreise. Raumforschung und Raumordnung (Spatial Research and Planning). 77(6): 617–638. DOI: 10.2478/rara-2019-0043. (not part of this dissertation)