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Innovation Modes in SMEs:

Mechanisms integrating STI-Processes into DUI-Mode learning and the role of regional innovation policy

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Abstract:

Innovation processes consist of interactive learning mechanisms that combine different knowledge sources. Using a set of 72 exploratory interviews with small- and medium-sized enterprises (SMEs) and regional innovation consultants, this paper analyzes the combination of STI (science-technology -innovation) and DUI (innovation based on learning-by-doing, -using and -interacting) modes of innovation. We show that SMEs integrate STI-based knowledge into DUI-routines through mechanisms with varying levels of complexity. The mechanisms we describe differ with respect to a) effects on innovativeness, b) the absorptive capacities required and c) incurred costs. Based on these mechanisms, d) cognitive, organizational and financial barriers to combinatorial innovation modes are derived. We find that e) regional innovation consultancies play an important role in fostering combinatorial innovation modes. We therefore explore the role of regional innovation policy and its effects on firms' combination of innovation modes. Our findings point out innovation drivers that facilitate SMEs' capacity to absorb STI-based knowledge. Based on our empirical findings, we derive implications for innovation policy with regards to absorptive capacities in SMEs.

JEL: D23; D83; L10; L22; O31; O33; O38

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

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1 Introduction

In comparison to larger corporations, SMEs often innovate with lower or no explicit expenditures on R&D or R&D departments (Rammer et al., 2009; Brink et al., 2018). Additionally, SMEs produce rather incremental innovations, which require different inputs and combinations of knowledge unlike radical innovations (Freeman, 1994). Moreover, innovation is a cumulative and interactive learning process, requiring more than firm internal knowledge dynamics. Therefore, it often requires a combination of different resources and the involvement of a variety of actors (Grillitsch and Rekers, 2016; Asheim et al., 2016). Recent work shows that firms combining different ways of knowledge-creation and learning processes are more likely to introduce product and process innovations (Thomä and Zimmermann, 2019). A recent contribution to different types of knowledge-creation was made by Jensen et al. (2007). They introduced STI (science-technology-innovation) and DUI (doing-using-interacting) mode of innovation in order to explain a firm's innovativeness with regard to 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 et al., 2016 for reviews). Successive contributions have shown that a combination of both innovation modes leads to higher innovation outputs (Fitjar and Rodríguez-Pose, 2013; Aslesen and Pettersen, 2017). Most studies measure the combination of DUI and STI modes by the frequency, intensity or importance of several firm-internal and external interaction patterns. However, little is known about the internal changes undergone by firms in learning routines and the difficulties of combining innovation modes related to the combination of different types of knowledge. As innovation modes are based on different types of knowledge, innovating in different innovation modes is related to the idea of diverse knowledge bases (Aslesen and Pettersen, 2017). The underlying knowledge base as well as the way knowledge is created and sustained differs with respect to different innovation modes. A combination of innovation modes can be difficult for SMEs, as they often have little or no science-based learning routines (Nunes and Lopes, 2015; Bennat and Sternberg, 2019). This results in a lower absorptive capacity (Cohen and Levinthal, 1990) to integrate STI-based knowledge into a firms' DUI mode of innovation. The aim of this paper is to analyse mechanisms that non-R&D-based SMEs use to combine innovation modes on a microlevel and how this process can be supported by regional innovation policy.

Using a set of 72 exploratory interviews with SMEs and regional innovation consultants, this paper contributes to a better understanding of why and how SMEs that innovate primarily through learning-by-DUI, make use of learning-by-STI. We explain how this combination is reflected in changes in firm-internal learning processes. We show how SMEs search for and integrate new knowledge into their innovation process using magazines; employee knowledge and R&D collaborations. These insights are combined with our findings on regional innovation policy activities and its role in knowledge integration. Hence, we investigate the role of regional innovation consultancies in affecting firms' combinatorial innovation modes and firms' demands for policy changes on a regional base. Often, regional innovation consultancies act as an intermediary between R&D partners and SMEs by establishing cooperation. The process of cooperation establishment amongst different actors, of knowledge creation and its effective integration in firms' innovation processes are explained.

The remainder of this paper is structured as follows: the next section introduces our conceptual framework and provides a literature review. In Section 3, we describe our methodology and our qualitative data collection, while in section 4 the results of our analysis are presented. The last section discusses and summarizes the findings and presents policy implications.

2 Theoretical Concepts and Literature Review

2.1 The DUI and STI mode of innovation

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, i.e. learning from work experience and increasing skills in production (Arrow, 1962; Thompson, 2010), using, i.e. feedback from users and their involvement in improving products and services (Rosenberg, 1982); and interacting, i.e. as a product of interaction between firms, suppliers and competitors as well as other actors (Lundvall, 1985; Jensen et al., 2007). Innovation outputs are often incremental productivity gains, such as cost reductions or quality improvements, but 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, based on HRM practices (Apanasovich et al., 2016; Jensen et al., 2007; Nunes and Lopes, 2015; Parrilli and Heras, 2016; Apanasovich et al., 2017).

In contrast, innovations in the STI mode 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 are of vital importance for the generation of innovation in the STI mode (Isaksen and Trippel, 2017). The STI mode of innovation is generally associated with the production of radical innovations (Nunes and Lopes, 2015). Learning-by-searching is an important component of learning from science such as internal R&D (Johnson, 2010). Without an internal R&D department, the procession and accumulation of scientific knowledge from outside of the firm is less likely to occur (Amara et al., 2008; Cohen and Levinthal, 1989). Therefore, to increase their overall innovation performance, the integration of STI-Elements into non-R&D firms is an important goal of innovation policy.

2.2 *Combination of Innovation modes*

Research on different modes of innovation shows that they are not mutually exclusive. Most studies on innovation modes state that a combination of both modes or the use of multiple sources have a positive impact on innovation outcomes (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). Only a few studies cover mechanisms of how and why firms combine innovation modes and what problems are associated with the combination of both innovation modes (Aslesen and Pettersen, 2017; Isaksen and Karlsen, 2013). Consequently, little is known about the internal learning mechanisms in SMEs, resulting in the effectiveness of combinatorial innovation dynamics.

For example, Nunes and Lopes (2015) analyse the combination of DUI and STI in smaller firms, highlighting the importance of different types of knowledge for innovation outcomes. According to their findings, firms with medium technological intensity or those operating in knowledge services tend to prefer informal interaction and learning mechanisms. Further, those firms value territorial interaction and have a lower degree of technological complexity, but combine DUI traits such as “placing the product on market” with STI traits of “transformation” and “knowledge production” (Nunes and Lopes, 2015, p. 1810). This is in line with Parrilli and Heras (2016) confirming that a combination of STI and DUI mode impacts innovation outputs. However, independent STI mode firms are more likely to produce technological innovation, whereas independent DUI mode firms are more likely to produce non-technological innovation. The role of SMEs in this picture is not treated separately, but firm size, measured by number of employees, has a significant effect on innovative outcomes for every innovation mode.

Apanasovich et al. (2017) have recently addressed the question of how SMEs mix different modes of innovation in order to produce innovations. They propose the RTH (Research-Technology-Human Resource Management) model with new measurements related to the previously established DUI and STI mode. They identify different drivers of innovation in 51 SMEs from the IT sector and build innovation profiles in order to analyse possible combinations within their RTH framework. After a cluster analysis, they identify three archetypical modes of innovation: low learning mode, S&T-based mode and creative organizations. Firm-internal learning mechanisms were also addressed by Clarke and Winch (2006, p. 15), who explain that a firm’s workforce competencies are raised by “the ability to apply theoretical knowledge in a practical context”. This is especially fostered in the German Vocational- Education- and Training –System (VET) using workplace learning (Solga et al., 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).

Aslesen and Pettersen (2017) analyze six entrepreneurial firms in STI and DUI mode clusters in Norway and explain their innovation history. The respective firms started out by using either the DUI or STI mode of innovation and made use of the other mode of innovation or a combination throughout the innovation process. They conclude that combining different knowledge bases and innovation modes was crucial for the success of the innovation process. They also state that entrepreneurs need different cluster facilitation. Thus, cluster facilitation should strengthen cumulative knowledge creation with respect to the firms’ innovation mode apart from promoting knowledge exchange and learning interactions between the two modes.

Summarizing existing literature, we see that a combination of both innovation modes leads to more innovation. Although previous studies explore how firms combine different types of knowledge in practice, little is known about firms’ internal change of learning routines and the characteristics of different ways of innovation mode combination. Hence, this paper contributes to existing DUI literature given its strong connection with ideas of regional innovation systems and firm internal management processes. In line with contributions by Apanasovich et al. (2017) as well as Isaksen and Karlsen (2012) on innovation modes in SMEs, we further explore how non-R&D based SMEs successfully combine innovation modes, the mechanisms crucial for a successful combination and how regional innovation policy can support the integration process. With the political goal of fostering innovation output at a regional and national level, an understanding of internal mechanisms is especially important. As a consequence, this knowledge offers practical insights for the promotion of a better combination of innovation modes through regional innovation policy (Isaksen and Karlsen, 2012; Apanasovich et al., 2017; Aslesen and Pettersen, 2017).

2.3 *The role of regional facilitators*

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. SMEs usually undertake small investments when incrementally changing current products but are wary when it comes to high investments regarding new developments (Rammer et al., 2009). New developments are associated with higher returns but also pose tremendous risks in need of balancing. SMEs often cannot afford to spend large amounts of money on internal R&D departments or large R&D projects which are not state-funded. Having no R&D departments saves SME resources (Rammer et al., 2009). At the same time it might lower a firm’s absorptive capacity (Cohen and Levinthal, 1990) for external R&D activities, when no recruitment from the academic system takes place (Herstad et al., 2015). This conflict between work routines, existing knowledge and new external knowledge can be an obstacle to the combination of 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 into an STI mode of innovation (Isaksen and Nilsson, 2013). As innovation is the result of complex, interactive and cumulative learning processes (Asheim et al., 2016), it involves knowledge dynamics between a variety of actors, also driven by unique regional framework conditions (Boschma, 2005). These regional framework conditions continue to be shaped by policy makers to create competitive advantages (Martin et al., 2011). While competitive advantages are constantly under pressure for change, regional policy makers support interactive learning, and hence regional cooperation (Martin et al., 2011, p. 552).

This is in line with the regional innovation system approach (RIS). The RIS approach emphasizes the importance of geographic proximity for knowledge exchange, as well as the role of regional governance. More specifically, it takes into consideration the regional economic, social and institutional factors that affect a firm’s learning processes. The approach involves not only formal but also informal cooperation of private firms, governmental agencies, universities or other public research institutions (Asheim et al., 2016). RIS consists of regional and national knowledge infrastructures that influence how actors learn in innovation systems (Isaksen and Trippl, 2017), as well as their absorptive capacity, enabling them to integrate new knowledge (Asheim et al., 2016). The configuration of an innovation system, its openness and the capability to combine regional and national networks influences competitive advantages in the knowledge economy. However, this original RIS concepts leads to an STI mode of policy framing (Cooke, 2014). Indeed, previous studies have shown that firms innovating in different modes and seeking knowledge from different external knowledge sources, may need different types of support infrastructure. STI-firms mainly rely on R&D activities in universities, research institutes and firms’ R&D departments. This is in line with a narrow definition of RIS (for example Lundvall, 1992; 2007), whereas, for DUI-firms, a broader definition (Cooke, 2014) that includes ‘all the actors and activities that affect learning, knowledge creation and innovation in a region’ (Isaksen and Karlsen, 2013) is more appropriate. Due to this broader definition, 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 in cooperation between firms, knowledge organizations and consultancies (Isaksen and Karlsen, 2013). Empirical results of previous studies about the role of geographical proximity for both innovation modes are difficult to summarize within a single framework (see for example Isaksen and Trippl, 2017; Johnsen and Isaksen, 2012; Tödtling et al., 2007; Fitjar and Rodríguez-Pose, 2013; Aslesen and Pettersen, 2017). Depending on the organizational thickness and diversification of a specific RIS, the size of the enterprise, its knowledge base, innovation mode, and the geographical source of new knowledge varies (Aslesen and Pettersen, 2017; Isaksen and Trippl, 2017). We suggest that interaction on the regional level matters for SMEs, especially with regards to affordable human and financial resources required to cover transaction costs. 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 and Pettersen, 2017).

Governments are aware of this fact and have established local services especially for SMEs to increase productivity and innovativeness by overcoming their limited “internal specialized ‘information processing’ capacity” (Toner, 2011, p. 62). It raises the question of how SMEs that predominantly apply learning-by-DUI get in touch with STI-partners, especially if they are not located in regional proximity of the respective SME. Given the increasing importance of knowledge and technology transfer for innovation policy, we assume that regional innovation consultancies play a crucial role in connecting DUI-mode SMEs with STI-partners, thus upgrading their capacities to integrate STI-based knowledge into their innovation processes. Therefore, it is necessary to analyze the role of regional facilitators in innovation processes. Hence, our research questions are (1) how and why do SMEs combine DUI mode routines with STI mode learning processes and (2) how and why do regional innovation consultancies affect firms’ combinatorial innovation modes?

3 Method and Data

Given the research gap identified above, we choose an exploratory qualitative approach, which is best suited for research that addresses “how” and “why” questions and for building theory (Eisenhardt, 1989; Eisenhardt and Graebner, 2007). We used qualitative interviews as an insightful tool for analyzing the reasons for and the mechanisms behind innovation mode combinations. Moreover, case studies help uncover the structure of regional innovation systems and the complex generation of new knowledge and its spillover. Our qualitative approach enriches previous quantitative studies on innovation mode combinations in order to shed light on complex social phenomena, such as firms’ knowledge creation and learning processes as well as current regional innovation policy.

In order to investigate how and why non-R&D based firms combine DUI-mode learning with STI-based knowledge, we use a criterion-oriented, purposive sample of firms that innovate predominantly in the DUI-mode, expanding into the use of STI-related knowledge. We applied snowball sampling in order to acquire similar case firms, since interference between the cases could be negated (Schreier, 2007). Further, we extended the cases with interviews of regional innovation consultancies, whose principle tasks were to establish knowledge networks and increase absorptive capacities in regional SMEs. We use this second group to compare insider and outsider views. Following Karlsen and Larrea (2018) and their idea to integrate a co-generation framework into regional innovation policy, this paper merges context-related-knowledge of regional innovation consultancies, experience-based knowledge of local SMEs and theoretical knowledge from the research team to set free ‘collective knowing’ about combinatorial innovation modes.

We focused on the three German planning regions (‘Raumordnungsregionen²’) Goettingen, Hanover and East-Thuringia to cover three different Regional Innovation Systems. All regions include metropolitan areas, implying ‘organizationally thick’ Regional Innovation Systems, but their economic structures are based on different specializations (Isaksen and Trippel, 2017, p. 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.

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 agencies³. Our questionnaires are documented in the appendix. As the research interest was to find patterns between the interviews which are not industry specific, we included SMEs from different industries and sectors (see Tab. 3). After an initial problem analysis using previous theoretical and empirical contributions, we summarized core aspects of our research into two interview guidelines that consisted of open questions (Flick, 2017): one for SMEs and one for consultants. We tested the questionnaires in pilot-interviews, upon which we trained interviewers and refined our questions (Mayring, 2010). The interviewees were asked to explain in detail how innovation with and without R&D activities takes place. We also enquired about factors which were used in previous DUI-studies which were not stated by interviewees initially, to investigate their relevance for our interviewees. Anonymity was ensured to all interviewees. The interviews were recorded and transcribed afterwards. Using these transcriptions, we conducted a content analysis (Mayring, 2010), 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 new to us. We further condensed the codings into summaries and inductively developed more nuanced subcategories. Those, in turn, are used for the analysis, upon which the results are built. We cite statements made by SMEs with a ‘U’ and from regional innovation consultancies with a ‘C’, followed by the number of the interview in accordance with our internal data base.

² Functional division of analytical grids in Germany based on districts and commuting flows.

³ Interview Sample: Goettingen: 10 RICs/ 14 SMEs; Hanover: 12 RICs/ 14 SMEs; East- Thuringia: 9 RICs/ 13 SMEs

Table 1. Overview of interviewed industries

Industry ⁴		No. of SMEs
Agriculture, forestry and fishing		1
Mining and quarrying		1
Manufacturing	Manufacture of food products/ beverages	4
	Manufacture of computer, electronic and optical products	11
	Manufacture of fabricated metal products, except machinery and equipment	4
	Manufacture of machinery and equipment n.e.c.	4
Construction		2
Wholesale and retail trade; repair of motor vehicles and motorcycles		4
Transportation and storage		1
Information and communication		6
Professional, scientific and technical activities		5
Human health and social work activities		1
Administrative and support service activities		1
Σ		41

4 Results

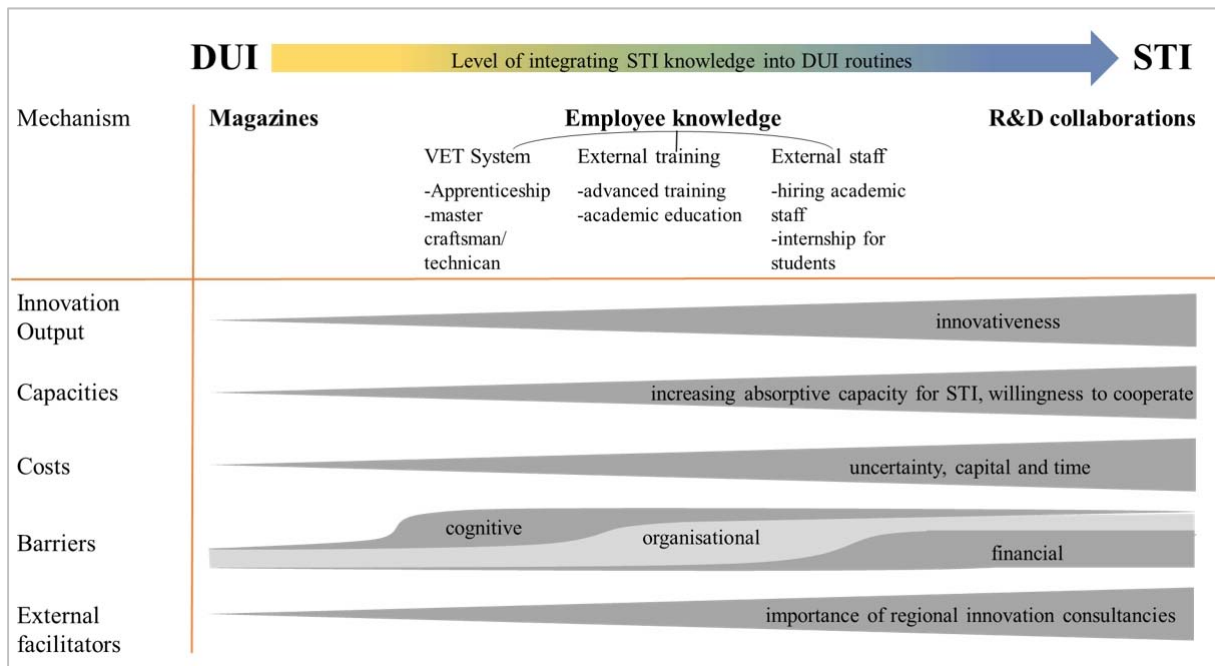
We deduce mechanisms of combinatorial innovation modes, based on the different sources of STI knowledge described by the interviewees. The mechanisms are: i) use of trade magazines; ii) employee training and knowledge and iii) R&D collaborations. The following chapter rates the mechanisms according to their complexity. We start with the easiest integration of STI-based knowledge and end with the most difficult integration of STI practices. All analysed mechanisms entail five dimensions: a) innovative results of mechanisms, b) required capacities, c) involved costs, d) barriers related to the use of previously mentioned categories, and e) the role of regional facilitators with regard to the relevant mechanisms.

As shown by the literature review in chapter 2, more complex mechanisms like R&D collaborations generally produce more innovative results. At the same time, a higher level of integration of STI-based knowledge into DUI practices requires more complex capacities in order to successfully use new (scientific) knowledge. Likewise, the risk of failure to successfully integrate STI-based knowledge increases with the complexity of the mechanism. It results in a loss of resources given the rising costs and time required for the activities involved. We also find various barriers to combinatorial innovation practices. We detect an underlying structure of cognitive, organizational and financial barriers to a combination of innovation modes. These are in line with the continuum of combinatorial innovation modes but differ in intensity, depending on the analyzed mechanism.

These perceived barriers raise the importance of available external advice and help. We analyze the interviews of the SMEs to explore an insider view of the practical barriers to combinatorial innovation modes. As the regional innovation consultancies could overestimate their importance for the combination of innovation modes, 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 understand the possible range of problems that SMEs are confronted with. Figure 1 illustrates the continuum of combinatorial knowledge mechanisms and the extent to which the discovered barriers are relevant at different levels of STI-knowledge integration with DUI mode routines. A detailed description of the mechanism and their dimensions is provided in the following.

⁴ Industry classification referring to the NACE Rev. 2 statistical classification of economic activities in the European Community.

Figure 1. Continuum of combinatorial innovation mode mechanisms



4.1 Codified knowledge in trade magazines

Trade magazines are a common source of codified information about new developments. We classified ‘using trade magazines’ as the mechanism that constitutes the lowest level of integrating analytical knowledge into DUI practices. Though codified, they represent the most accessible and cheapest form of technological knowledge. They allow firms to capture ideas, either from reports on new technologies or developments in the market.

One reason for the use of trade magazines is, that firms without an explicit R&D department do not possess absorptive capacities and usually rely on experience-based knowledge (U17, U21, U25, U29, U37). Thus, the term ‘trade magazines’ excludes academic journals. Trade magazines offer a general overview of new technological developments and therefore, codified technological knowledge. Despite this offering, trade magazines are more compatible with a user-driven mode of innovation as they contain information about market developments. DUI firms possess the appropriate knowledge base to apply knowledge from trade magazines to their firm-specific context. Trade magazines were not a single source of information, but usually existed in combination with trade fairs and competitors to learn about new technology and developments in the market. A search for new developments, using journals alone, is neither sufficient nor does it happen systematically: “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. (U31) The underlying motivation is to have a quick overview of new developments that take place in the market and to screen competitors and customers for the necessity and usefulness of adapting to new technological developments. The combination of trade magazines with other sources about market developments makes sense as these rely on learning-by-DUI and therefore, follow a user-centric approach.

The innovativeness that results from this mechanism is low as applicable ideas or knowledge often requires more than reading. The use of trade magazines requires no elaborated firm-internal 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. Though important, codified knowledge in the form of trade magazines has limitations. Firms rely on their firm-internal knowledge when using them to combine the DUI and STI mode of innovation. However, a firm’s knowledge base and absorptive capacities predetermine the types of codified knowledge the former can effectively use for innovations.

Hence, we argue that this mechanism of combinatorial innovation modes 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 comes along without any ‘real’ interaction of different actors. SMEs which only used this method of STI integration explained that regional innovation consultancies are less important for their innovation activities (U19, U24, U34).

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 (U33). 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. A more formal, not firm-based education is usually accompanied by a lower compatibility with a firm's know-how.

A major topic of learning-by-training is vocational education and training (VET). Apprentices in their early years were not mentioned as a major source of innovations in our interviews. However, VET training relies on a combination of analytical and synthetic knowledge and SMEs rely on the know-how of apprentices when they finish their degree, for example for every-day problem solving (U28). SMEs need apprentices to transfer their firm-internal know-how to them and sustain their firm-internal routines and capacities. With regards to costs, SMEs prefer to hire employees for VET training from their region who intend to stay within the region (U16). 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. Firm-based education as well as further professional training was one popular way to supplement a firm's know-how with further analytical knowledge (U7).

Firms who mainly operate in the DUI mode of innovation view further external training as another way to source new scientific and technological knowledge (U6, U7, U24). In case employees experience limitations in knowledge or expertise, they ask for workshops tailored to their needs to increase the boundaries of their analytical knowledge (U7, U24, U29, U30, U31). In both cases, further training serves to increase a firm's capacity and to motivate employees. With regard to innovativeness, employees learn how to operate new or current machines more effectively, learn of new developments in quality management or customer interaction (U29, U30). Furthermore, some employees suggest improvements to current products or processes, based on insights from workshops (U7). A common practice is to send employees familiar with routines to external workshops to facilitate learning-by-training. These opportunities guaranteed that external knowledge from workshops was successfully absorbed. Costs included financial costs in terms of workshop fees as well as payment for employees who are absent from their workplace. However, the outcome in terms of new skills and knowledge makes it a positive investment (U24, U28, U43).

Firms can advance their related absorptive capacities by hiring new employees with a different education. Thus, another way to integrate STI knowledge was to recruit external staff. The interviewed SMEs hire students for part-time jobs or offer internships.

Part-time students did not contribute to a firm's innovativeness. This had several reasons. Merely being a student was insufficient for a transfer of university knowledge. This is explained by a lack of practical knowledge and shows that, with regard to innovativeness, part-time students are less important. Students need to get acquainted with a firm's routines in order to apply analytical knowledge from a university to a practical context. ICT-students who are capable of quickly introducing process innovations are an exception to this (U42). Following this, 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 with regard to process innovations. Students with other backgrounds would nonetheless play a crucial role after some time. Employing students is one way to develop a firm's knowledge base by adding new knowledge. As one CEO 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" (U29). Once SMEs reach the limits of their current production possibilities, adding part-time students as new employees with a background in analytical knowledge expands a firm's know-how and therefore its absorptive capacities for new knowledge. However, this knowledge must be incorporated into the work routine of the firm, a process that can be troublesome.

Offering internships was another way to employ students from universities. Internships were based on mutual interests: "Students need an internship so they come to us. We also want students, because we need highly educated employees, with potential, because we need this quality [of knowledge]" (U18). 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 having become familiar with a firm's routines. However, internships do not expand a firm's absorptive capacities through a 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 as well in terms of resources, as internships can result in the absence of long-term employees from their workplace for training purposes.

Given an increasing level of integration, organizational barriers hamper innovativeness: In the case of the mechanism 'employee knowledge', evidence was found in both sample groups that SMEs, that predominantly innovate in the DUI-mode, have a different way to organize innovation processes than STI-firms (C30, U29). Having fewer human and financial resources, a capability of organizing 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 STI-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 to 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 (U33). 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 right contact person at universities although he underwent an academic education in the respective region. He described that he is far from integrating university-knowledge (U33). 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 (U27, C16, C4, C6). Being indirectly involved in the daily work of the SME, we identify that a 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.

4.3 R&D collaboration

The highest level of STI knowledge integration were university ties and research collaborations. University ties could either be formal or informal, where the latter was often established during a CEOs previous education at a university (U22). SMEs in the DUI mode focus on one or a few development projects with external partners at a time and use them as a substitute for internal R&D (U1, C7). A major reason for initial R&D cooperation and projects is the possibility to launch an own product for the first time (U1). The outcomes of R&D projects therefore offer the highest innovation output, in comparison to other mechanisms of combining STI-related knowledge with DUI-routines (U1). SMEs know about the benefits of conducting in-house R&D. However, R&D departments are costly, and many SMEs cannot afford their own R&D department. R&D collaboration is one way to reduce the financial costs of in-house R&D. However, R&D collaborations do not mitigate the risks associated with innovative outcomes of R&D, and firms cannot be sure whether an R&D project delivers what it promises to.

One way to mitigate financial risks are state-funded collaborations. SMEs therefore use R&D funding to finance R&D projects in collaboration with universities and research institutes. Firms must finance a part of their R&D collaborations, making these collaborations expensive nonetheless. A comparatively long timeframe is another aspect of R&D-related costs. While R&D collaborations often innovate in long-term projects (around 5 years), SMEs have to offer product solutions far more frequently (U19). 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 worth the effort (U18, U36, U37). However, R&D projects also pose the problem that a firm might not be able to absorb the analytical knowledge produced elsewhere – a lack of absorptive capacities. 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 (U37).” SMEs struggle to absorb analytical knowledge 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 regards differing mutual expectations. This highlights a gap between conjectures and actual knowledge about the other parties' 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). In contrast, SMEs neither addressed nor denied this reluctance (U18). Nevertheless, consultancies not only initiate knowledge exchange, they also accompany meetings, establishing trust to ask questions and to feel as 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 became 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 (U42). 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 (U32, C3). The consultancies also have access to different regional industry networks, allowing them to connect STI-partners with specialized SMEs (C3). It becomes clear that the 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, U19, U32). Further, one SME states that the consultancies are also mediators in case of conflicts between collaboration partners. For example, different interests in publication and secrecy of innovation results can hamper the collaboration between research organizations and firms (U34).

The biggest barrier to integrating STI knowledge into DUI mode firm using the mechanism of R&D projects is of financial nature. Even SMEs with experiences in combining innovation modes struggle to finance innovation projects. As our findings about the mechanism show, state funding can motivate DUI firms to cooperate with STI-partners. As funding of innovation project is available on different scales (local, regional, national and EU-level), applications for funding are often too complex to complete them independently (U34, U36, U40, U18, U24, U27, U29, U31, U32, U30, U13, U10). This tendency increases with the scale of fund application. One SME adds that regional innovation consultancies help SMEs to apply for funding, to specify innovation ideas and therefore, to write better applications which increase the chance of a positive response (U26). Especially DUI 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 consist of 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 (U36, U31). We learn 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 prizes: they "ennoble business plans", making it more likely to regain funding. Hence, local innovation contests conducted by regional innovation consultancies boost application for funding on the state level as well (U25).

5 Conclusion and Implications

As previous contributions to the innovation mode literature explored, a combination of the DUI and STI mode of innovation is often the most effective way to produce innovative outputs. Nevertheless, little is known about the mechanisms by which this combination takes place in practice and its associated problems. Knowledge about these mechanisms can be used by regional innovation policy actors to promote innovation activities.

In this paper, we explored the two research questions of 1) how and why SMEs combine different modes of innovation and 2) how and why regional innovation consultancies affect firms' combinatorial innovation mode. We applied a qualitative research approach involving 77 interviews with firm representatives and regional innovation consultants in three regions in Germany. We observed different levels of integration of STI knowledge into predominantly DUI mode innovating SMEs. Sorted by the complexity of integration process, the three following mechanisms were found: i) use of trade magazines, ii) use of employee knowledge (VET system, employee training, hiring external staff) and iii) R&D collaborations. A higher degree of integration of STI knowledge into DUI routines increases the innovativeness of the outcome but is accompanied by a higher need for absorptive capacities and higher costs. Furthermore, we found barriers that hamper 'knowledge upgrading' related to STI practices. 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. Our results show that regional innovation policy is not restricted to financial services. Regional innovation policy can also support SMEs through matchmaking and reduction of cognitive barriers. Hence, we advocate the strengthening of policy activities that help overcome the identified barriers, instead of focusing only on university technology transfer.

Based on our qualitative interviews, we explored and described how SMEs manage to combine the DUI and STI mode of innovation. SMEs were analysed as they are often customer-driven (Hippel, 1998; 2005) and rely on the DUI mode of innovation in order to produce user driven improvements. They incorporate STI components if

necessary and suitable to their own or their clients' interests. We found several possible ways in which SMEs make use of analytical knowledge and incorporate it into their routines.

As the interviews have highlighted, SMEs that rely on experience-based knowledge and whose workforce had no university background face greater obstacles when trying to combine both innovation modes by using R&D collaborations. This is in line with Barker and 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 which 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 which is often too far detached from their experience-based knowledge and not directly helpful in their innovation processes. We argue that, given the technological trajectories (Dosi and 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 mode of innovation. This statement implies that there might not only be two faces of R&D (Cohen and Levinthal, 1989), but also routines of learning specific to the DUI mode of innovation that allow firms to capture DUI-specific knowledge.

Barriers to successful collaborations are a result of partnerships that possess different knowledge bases that are difficult to combine. For firms trying to implement knowledge related to the other mode of innovation, 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 we detect. We conclude that funding should also support innovation processes in DUI mode firms and their access to analytical knowledge. This could additionally increase the absorptive capacity of SMEs related to technology, in comparison to 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, making it easier to implement STI-related techniques of innovating. This corresponds to Isaksen and 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 labour force and "upgrade" the existing industry (Isaksen and 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, p. 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 aid firms in finding their own path to new knowledge. One example can be the stimulation of recruiting academic employees in order to increase absorptive capacities and minimize cognitive and organizational barriers between DUI-firms and STI-partners, as suggested by Isaksen and 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 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 seems to have not improved until now. As the funding system still fails to match SMEs' needs, we also point out that cognitive and organisational barriers exist. This increases the importance of external facilitators. However, only a few consultancies offered instruments that addressed all levels of STI integration.

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 a 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 to accompany the knowledge exchange of DUI and STI-partners (U3). Keeping this in mind, we argue that not every single regional innovation consultant has to offer instruments that cover all barriers. But in times where innovation processes often cross traditional industry categories, it becomes especially important that regional consultancies interact, exchange knowledge and centrally coordinate offers between each other. Combining RIS literature with ideas of combinatorial innovation modes, 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 tended to be less well developed among regional innovation consultancies.

Finally, there are some 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 explore theoretical relations amongst different constructs and underlying mechanisms and derive a theory of how SMEs combine innovation modes. These theoretical relationships must be tested quantitatively in order to be reliable for a larger population. We advise regional policymakers to be careful when copying successful activities from other regions. In any case, one should consider each region's unique regional framework before implementing far reaching policies (Tödtling and Trippl, 2005). Further research is also needed in case one wants to measure the innovation inputs and outputs of combinatorial innovation modes, especially with regard to the DUI mode of innovation. As traditional innovation indicators mostly refer to an STI mode of innovation, DUI practices are often not considered. In order to generalize findings about the impact of combinatorial innovation mode mechanisms, we need more accurate indicators about DUI-mode learning processes and innovation outputs.

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7 Appendix

Interview Guidelines

1) 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 innovations did your firm – in a broad sense – produce?
- Do you conduct a systematic search for new (scientific) knowledge and methods?
- What kind of innovations 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 innovation?
- How does knowledge and experience exchange take place at your firm, especially during the production of goods and services?
- How do customers influence innovation and improvements?
- How does exchange with customers take place?
- How do competitors influence innovation and improvements?
- How does exchange with competitors take place?
- What role do other external actors (banks, regional consultancies, etc.) play for innovation?
- 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?

2) 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?