Volkswirtschaftliches Institut für Mittelstand und Handwerk an der Universität Göttingen

ifh Working Paper No. 23/2019

Measuring the 'doing-using-interacting mode' of innovation in SMEs - a qualitative approach

Harm Alhusen[a,*], Tatjana Bennat [b], Kilian Bizer[c], Uwe Cantner[d,e], Elaine Horstmann[c], Martin Kalthaus[d], Till Proeger[a], Rolf Sternberg [b], Stefan Töpfer[d]

[a] *Institute for Small Business Economics. Georg-August-University of Goettingen*

[b] *Institute of Economic and Cultural Geography. Leibniz University Hannover*

[c] *Chair for Economic Policy and SME Research. Georg-August-University of Goettingen*

[d] *Chair of Microeconomics. Friedrich-Schiller-University of Jena*

[e] *I2M Group, Department of Marketing and Management. University of South Denmark*

Abstract:

The 'doing-using-interacting mode' of innovation (DUI) is considered an important component of innovative activity. It describes informal innovative activities and thus complements the 'science-technology-innovation mode' (STI) based on research and development. While empirical measurement of the STI mode is well established, proxies for measuring DUI activities are still underdeveloped and no consensus has emerged concerning which intra- and extra-firm processes primarily constitute the DUI mode and how they should be measured. Based upon 81 in-depth interviews with German SMEs and regional innovation consultants, we propose a comprehensive set of 47 indicators comprising both established and new DUI processes for future empirical measurement. We argue that this measurement approach can lead to a more holistic understanding and ultimately quantifiable measurement of DUI innovativeness, which can guide further research and policymaking.

JEL: O3, O30, O31, R10

Keywords: DUI, Innovation indicators, learning processes, modes of innovation, STI

* *Corresponding author. Harm Alhusen, Institute for Small Business Economics. Georg-August University of Goettingen; Heinrich-Düker-Weg 6, 37073 Göttingen, Germany; Harm.Alhusen@wiwi.uni-goettingen.de; Phone: +49 551 39 174888*

1. Introduction

Innovative activities are the central determinant of national, regional and firm-specific competitiveness in modern knowledge-driven economies (Apanasovich et al., 2016b; Asheim et al., 2011; Tödtling et al., 2007). Assessing and measuring the underlying processes of learning and knowledge accumulation has therefore been an ongoing challenge for decades(Abramovitz, 1956; Dosi et al., 1988; Romer, 1990; Solow, 1957). For instance, this encompasses such diverse activities as informal learning processes or external interactions (Apanasovich et al., 2017). A central strand of literature within this broader trend discusses the differentiation of two ideal-typical modes of conducting innovative activities, namely the "science-technology-innovation mode" (STI) and the "doing-using-interacting mode" (DUI) (Jensen et al., 2007).

STI mode innovation typically relies on codified, 'know-what' and 'know-why' knowledge, is conducted by R&D departments, particularly in larger firms closely cooperating with institutions of knowledge production and tends to have a global reach. Learning in STI primarily means searching for new knowledge such as scientific principles and recombining knowledge to achieve substantial innovative progress. Therefore, formal R&D is the main driver of innovation, resulting in fundamental innovations in terms of new products or processes. While these domains of innovative activities are captured fairly well by the established indicators such as patents, R&D personnel and expenditures (Hall and Jaffe, 2018), DUI mode innovation cannot be described adequately by indicators focused on formal R&D activities due to its informal nature. Indeed, DUI is defined as resulting from tacit knowledge with a focus on 'know-how' and 'know-who', which tends to have a local reach in terms of its connections to customers, suppliers and competitors (Jensen et al., 2007). Learning is conducted through "doing", i.e. learning from working experience and increasing the skill in production (Arrow, 1962; Rosenberg, 1982). Furthermore, it involves "using", meaning e.g. feedback from users and their involvement in improving products and services (Rosenberg, 1982). Finally, it comprises "interacting", i.e. learning through interaction within firms and with external actors (Lundvall, 1985; Jensen et al., 2007). These three components result in innovations that are usually of an incremental nature such as cost reductions or quality improvements, but they can also generate new products, which are often highly customer-specific (Apanasovich et al., 2016b; Jensen et al., 2007; Nunes and Lopes, 2015; Parrilli et al., 2016).

Following (Jensen et al., 2007), a substantial number of studies have empirically investigated specific components and features of the DUI mode, while no comprehensive understanding has developed concerning which processes characterize the DUI mode. This hampers the quantitative assessment of DUI mode innovation and, therefore, its applicability for the improvement of low-threshold innovation support structures for SMEs. While the conceptional vagueness of DUI stems from the nature of the concept itself to some degree, we suggest that a qualitative approach exploring innovation and learning processes can substantially sharpen our understanding of the DUI mode. Using this approach, our paper's goal is therefore to identify the most important DUI processes within firms and propose items for an encompassing quantitative measurement. This, in turn, can inform the further development of innovation policy design of support structures for SMEs.

For our empirical assessment, we draw on small and medium enterprises (SMEs) from the 'German Mittelstand'. This sector of the German economy has been emphasized as exemplary for a strong innovative performance with limited resources, mostly without formal R&D (Massis et al., 2018; Pahnke and Welter, 2019). Following (Massis et al., 2018), its innovative performance is based upon six key traits, namely niche focus and customer collaboration, a globalization strategy, preferences for self-financing, a long-run mindset, superior employee relations and community embeddedness. We argue that these characteristics, particularly the niche and customer focus as well as a good and long-term employee relationship, capture key aspects of the DUI mode and that firms from the respective sector provide a good sample for an in-depth investigation of DUI processes. We conduct 49 in-depth semi-structured interviews with SME representatives to assess which firm-related processes are integral to the DUI mode. These firms are located in three German regions, namely Goettingen, Hanover and Jena. We complement this with 32 semi-structured interviews with innovation consultants to understand overarching pattern and regional particularities. This enables us to comment on indicators used in previous empirical studies, add novel indicators and describe links between the relevant processes. We further propose specific items that can be used to investigate DUI processes in future innovation surveys.

The remainder of this paper is structured as follows. Section two reviews the literature, summarizing previous measuring approaches to DUI and STI processes. Section three describes our qualitative methodological approach in determining the central DUI processes. Section four presents our results and suggestions for measuring DUI processes. Section five concludes and discusses policy implications and future research goals.

2. Research Context

2.1 The DUI-STI Dichotomy

Overall, the discussion on DUI/STI innovation modes and measurement revolves around an ideal-typical differentiation of innovation modes, as summarized in Table 1. Based upon this broad definition of the two innovation modes, overarching reviews of the literature have been conducted (Apanasovich, 2016a; Parrilli et al., 2016), yet no consensus has emerged regarding how DUI processes can be measured and which processes qualify as being representative of DUI learning.

Category	**science-technology-innovation mode**	**doing-using-interacting mode**
Type of knowledge generated and used	Analytical knowledge (scientific principles, discoveries and formulas)	Synthetic knowledge (practical, engineering-based purpose)
Core inputs	R&D expenditures, high-skilled scientific human capital and (advanced) technology	Accumulated, experience-based knowledge, learning processes and organizational arrangements
Core outputs	Radical product and process innovations	Incremental product and process innovations as well as commercial and organizational innovations
Type of interaction	Formal cooperation of firms with research institutes, universities, scientific brokers and foundations for the diffusion of scientific research	Formal and informal exchange within the firm, interaction with customers, suppliers and competitors
Principal approach to innovation	Investing resources to discover and test new product types, properties, qualities and configurations to produce fundamental innovations	Exchange and interaction among workers and clients, suppliers and service providers to incrementally improve existing products and services

Table 1. Ideal types of innovation modes according to main analytical categories (Apanasovich, 2016a; Nunes and Lopes, 2015; Isaksen and Karlsen, 2010)

Using this broad initial definition of DUI mode innovation as shown in table 1, we now describe the basic theoretical approach used in our analysis. In order to understand its fundamental learning processes and to derive indicators for the DUI mode, we use three different, well-established dimensions within innovation research that lend structure to our approach. Accordingly, all DUI processes drawn from the qualitative empirical base will be analyzed and structured according to the dimensions briefly described below.

First, we draw upon "learning-by-doing", where the economic implications of learning and improvement in performance over time were described by Arrow (1962). Thus, this part of our analysis focuses on daily working practices that foster incremental improvements within the firm that occur as a consequence and often by-product of everyday work. Second, learning-by-using is defined according to Rosenberg (1982), where customers or final users of a product or service can report back the experience from using the product. This provides learning opportunities from outside if the firm seeks such feedback from customers. Rosenberg (1982) provides several examples where the users reported their experiences and influenced the design of products. Such feedback – for which he coined the term "learning-by-using" – provides the basis for knowledge accumulation and innovation opportunities from outside the firm, which similarly plays a central role for DUI mode innovation activities. Third, learning-by-interacting takes place internally as well as externally to the firm (in accordance with Apanasovich, 2016a). Internal interacting describes knowledge creation and sharing mechanisms as well as human resource management (HRM) practices at the firm-internal level. It is therefore conceptually close to learning-by-doing but is considered as a separate learning process in the literature (Apanasovich, 2016a). External learning-by-interacting includes learning from suppliers, competitors and other actors that provide crucial knowledge or support for innovative activities. This deviates from the definition by Lundvall (1985) by extending learning-by-interacting to the intra-firm level, although it allows a clearer separation from learning-by-doing and learning-by-using. It is therefore in line with Johnson (2010) and Apanasovich (2016a) and most of the respective literature.

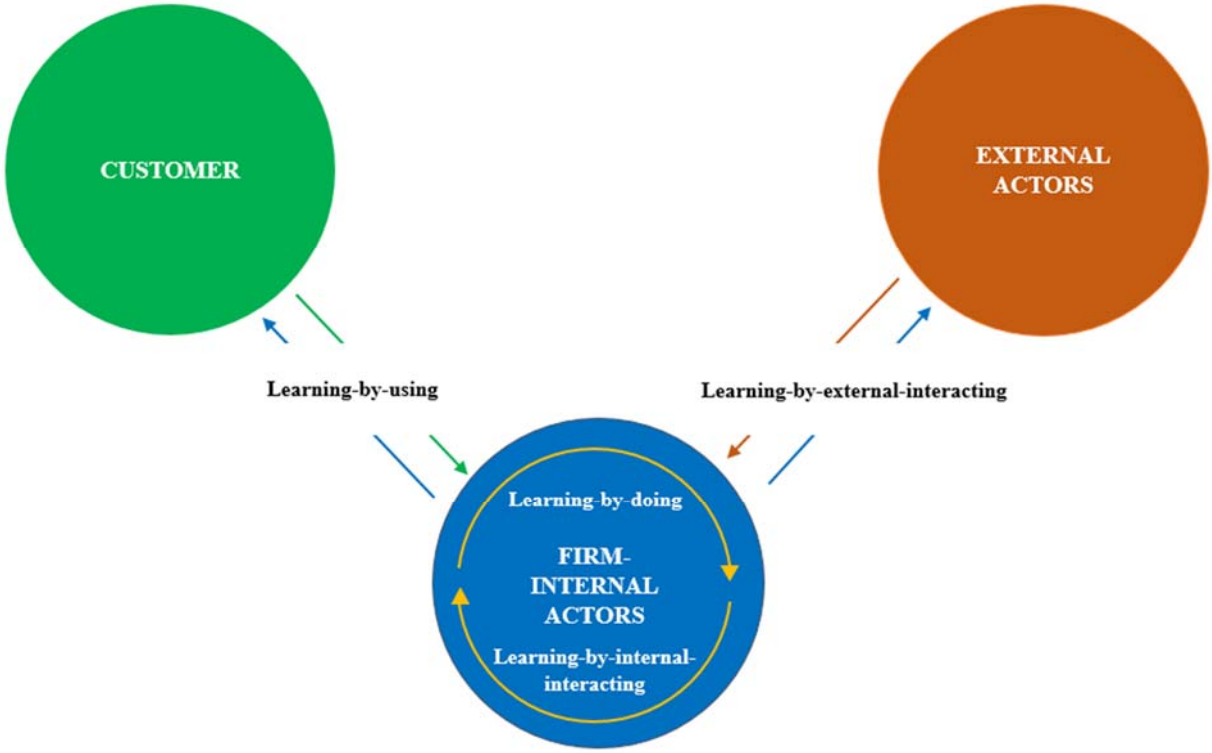

Figure 1. Dimensions of DUI learning

Figure 1 provides an overview of the three dimensions and the respective learning processes used to structure our analysis. Our interviews cover those dimensions and in particular the micro-learning processes between the different actors symbolized by the arrows. The ensuing analysis enables us to outline the central processes constituting the respective domains and to suggest measurement approaches. Turning to measurement items within the respective theoretical domains, previous studies have used both qualitative and quantitative approaches (Apanasovich, 2016a). To motivate our methodical approach to collecting DUI indicators, we review the existing qualitative and quantitative studies to offer an overview of the previously used measurement approaches.

2.2 Qualitative DUI Studies

Qualitative as well as mixes of qualitative and quantitative methods have focused on the regional characteristics of innovation modes, primarily looking into processes of interaction (Aslesen et al., 2012; Isaksen and Karlsen, 2012b, 2013). They typically start out by classifying the respective industries or regional clusters as being either DUI, STI or a mixed mode of innovation. Subsequently, the respective sectors are described based upon qualitative evidence regarding their innovation characteristics. Traditional manufacturing and specialized suppliers are categorized as DUI industries and they are often situated in peripheral regions, mostly relying on local knowledge and a highly specialized local labour market. High-tech industries like the biotechnology industry (Isaksen and Karlsen, 2010) are situated in core regions and cities with university campus and they are considered as classical examples of STI industries relying on knowledge from cooperation with universities and extra-regional actors (Isaksen and Trippl, 2017).

Apart from sectoral differentiations, qualitative studies in economic geography have analysed DUI processes from a regional perspective (Isaksen et al., 2018). Overall, the geographic location is shown to be another very important factor for firms' learning and innovation processes. Being embedded in a sub-national region where firms have access to local knowledge sources and are close to other actors or facilitating agents can increase learning and innovative activity (Boschma, 2005; Asheim et al., 2016). Thus, the embeddedness in a certain region offers firms a particular regional advantage with respect to their mode of innovation (Isaksen and Karlsen, 2013). A range of case studies further describes regions and their innovation modes according to core innovation processes, knowledge sources, and products (Isaksen and Karlsen, 2010, 2012a, 2012b; Aslesen et al., 2012). For instance, a recent study by Holtskog (2017) conducts three ethnographic in-depth case studies in the automobile industry to explore project-related innovation processes and the extent to which the respective processes are captured by several STI and DUI measures. Holtskog finds that firms' innovation processes cannot be characterized by a dominant innovation mode, that timing is a critical dimension when measuring innovation modes and that the two modes are deeply intertwined at the firm level.

Overall, qualitative studies on innovation modes tend to follow a regional and sectoral focus, often based on case-studies, whereby their results tend to confirm the initial theoretical contributions regarding the core characteristics of the DUI-STI distinction. However, we argue that no in-depth evidence regarding the intra-firm processes is collected that extends substantially beyond the general differentiation and characteristics of DUI vs. STI.

2.3 Quantitative DUI Studies

Quantitative DUI studies use different forms and aspects of DUI and STI mode learning as independent variables to investigate the relation between innovation modes and innovation outcomes. Methodically, most studies cluster firms into DUI, STI or a mixed mode of innovation according to their internal or external interactions. These different modes of innovation are then linked to innovative outcomes such as product, process, or organizational innovations. Resulting from this approach, a combination of innovation modes is considered most effective in fostering innovation outputs (Apanasovich, 2016a; Parrilli et al., 2016). By contrast, a more recent contribution (Haus-Reve et al., 2019) shows that DUI and STI learning can be substitutes with regards to external interaction, making a firm more successful when focusing on one of the respective modes.

Quantitative approaches to measure DUI have largely used established indicators and interpreted them as constituting important aspects of the DUI mode. Jensen et al. (2007) provide distinctive examples when describing learning-by-doing and using, although they also state that learning-by-doing and using both "involve interaction between people and departments" (Jensen et al., 2007, p. 684). Consequently, the majority of quantitative studies aim to measure DUI innovativeness based on a firm's internal or (most commonly) external interactions (Apanasovich, 2016a). A number of other quantitative studies have adopted an approach similar to Jensen et al. (2007) by describing the DUI mode as a holistic concept , i.e. using indicators of either learning-by-doing, using and interacting as representative for the DUI mode of innovation as such (González-Pernía et al., 2015; Parrilli and Heras, 2016). The limited number of studies aiming to measure learning-by-doing and learning-by-using tend to items such as expenditures for preliminary marketing efforts that are not or only loosely related to the concept of learning within DUI processes and, thus, might not adequately capture them (Apanasovich et al., 2016b). Other studies solely focus on external interaction and therefore omit the measurement of internal interaction as well as learning-by-doing and learning-by-using (Chen et al., 2011; Fitjar and Rodríguez-Pose, 2013; González-Pernía et al., 2015).

Table 3 offers an overview of previously used DUI indicators in the quantitative domain, summarized and classified into the four categories of learning-by-doing, -internal interacting, -using, and learning by external interaction.

Category	Indicator	Reference
Learning-by-doing	Expenditures on (preliminary) marketing efforts and product promotion efforts	Amara *et al.* (2008); Apanasovich *et al.* (2016b); Marzucchi and Montresor (2017)
	Competence upgrading through daily work and development via trial-and-error	Herstad and Brekke (2012); Thomä (2017)
	Development of new technical solutions	Thomä (2017)
	Sales outside the country	Amara *et al.* (2008)
	Training and workshops	Apanasovich *et al.* (2017); Rammer *et al.* (2009); Thomä and Zimmermann (2019)
Learning-by-internal-interacting *Informal mechanisms*	Learning through team efforts, spontaneous/informal collaboration and mutual support	Apanasovich *et al.* (2017); Herstad and Brekke (2012); Parrilli and Elola (2012); Rammer *et al.* (2009); Thomä and Zimmermann (2019)
	Team meetings to discuss ideas and goals related to innovation (collective creativity)	Parrilli and Elola (2012); Rammer *et al.* (2009); Thomä and Zimmermann (2019)
	Own idea collection and employee creativity	Fu *et al.* (2013); Thomä (2017)
	Less differentiated groups/departments or cooperation between departments/firm units	Jensen *et al.* (2007); Nunes and Lopes (2015); Thomä (2017)
	Importance of employees outside of R&D departments	Chen *et al.* (2011)

	Stimulation of internal competition between projects	Thomä (2017)
Formal mechanisms	Lateral and vertical communication/ communication policy involving the entire organization	Apanasovich *et al.* (2017); Parrilli and Elola (2012)
	Decentralization, more individual responsibility and autonomous work groups	Apanasovich *et al.* (2017); Jensen *et al.* (2007); Rammer *et al.* (2009); Thomä (2017)
	Use of quality circles/groups	Jensen *et al.* (2007); Nunes and Lopes (2015); Rammer *et al.* (2009)
	Formal system of collecting, selecting and managing proposals from employees	Jensen *et al.* (2007); Nunes and Lopes (2015); Parrilli and Elola (2012); Rammer *et al.* (2009)
	Reward system and incentive schemes	Apanasovich *et al.* (2017); Rammer *et al.* (2009); Thomä (2017)
	Use of multidisciplinary teams and/or formalized development process	Nunes and Lopes (2015); Parrilli and Elola (2012)
	Staff exchange programs between departments	Rammer *et al.* (2009); (Thomä and Zimmermann, 2019)
	Use of reverse engineering	Fu *et al.* (2013); Nunes and Lopes (2015)
	Use of integrated functions	Jensen *et al.* (2007); Rammer *et al.* (2009); Nunes and Lopes (2015)
Learning-by-using	Collaboration/interaction with or importance of customers, clients, lead users or users	Apanasovich *et al.* (2016b); Apanasovich *et al.* (2017); Chen *et al.* (2011); Fu *et al.* (2013); González-Pernía *et al.* (2015); Herstad and Brekke (2012); Jensen *et al.* (2007); Gruner and Homburg (1998)(Gruner and Homburg, 1998); Marzucchi and Montresor (2017); Nunes and Lopes (2015); Parrilli and Heras (2016); (Thomä and Zimmermann, 2019)
Learning-by-external-interacting	Collaboration/interaction with or importance of suppliers	Apanasovich *et al.* (2016b); Apanasovich *et al.* (2017); Chen *et al.* (2011); Fitjar and Rodríguez-Pose (2013); González-Pernía *et al.* (2015); Herstad and Brekke (2012);Marzucchi and Montresor (2017); Parrilli and Heras (2016); (Thomä and Zimmermann, 2019)
	Collaboration/interaction with or importance of competitors	Apanasovich *et al.* (2017); Chen *et al.* (2011); Fitjar and Rodríguez-Pose (2013); González-Pernía *et al.* (2015); Marzucchi and Montresor (2017); Nunes and Lopes (2015); Parrilli and Heras (2016); Thomä (2017)
	Collaboration/interaction with or importance of parent company	Fu *et al.* (2013); González-Pernía *et al.* (2015)
	Importance of trade fairs, trade press, industry associations or conferences	Marzucchi and Montresor (2017); (Thomä and Zimmermann, 2019)
	Inclusion of external partners in projects	Thomä (2017)
	Importance of personal relations	Nunes and Lopes (2015)

Table 3. Categories and indicators used to measure the DUI mode of innovation

Overall, our assessment of indicators used in the previous literature enables us to suggest that qualitative approaches to the DUI mode of innovation tend to rely on regional- and firm-specific conditions and – while characterized by strong internal validity – they provide little generalizable evidence on the entirety of firm processes that could be used to measure DUI processes. Quantitative approaches currently strongly rely on existing measurements of either internal or external interactions and thus cover only specific parts of the DUI mode of innovation. Thus, our contribution to the literature comprises weighing the different indicators previously used in the literature and adding new indicators by conducting extensive in-depth interviews on the working mechanisms of DUI mode learning.

3. Method

3.1 General approach

To achieve this research goal, we used an exploratory qualitative research design, based on in-depth, semi-structured interviews. The amount of qualitative research in economics was traditionally unimportant when compared to qualitative work, but is currently becoming more popular in economics (Starr, 2014). In general, we based our qualitative procedure on the description of problem-centered interviews by Mayring (2002).Using the literature on DUI measurement as a starting point, we developed interview guidelines for firms and regional consultancies that cover the current state of DUI indicators and prompts the interviewees to explain the respective learning processes at play in their innovative activities. These guidelines can be found in the appendix. After creating our questionnaires, we used them in pilot studies to train our interviewers and improve our questionnaires if necessary. We thus examined the role of previous DUI conceptions and encouraged respondents to share their own views and experiences. This open qualitative approach enables us to provide a more comprehensive picture of DUI mode learning within SMEs and regional innovation networks. After our initial pilot phase, we conducted face-to-face semi-structured interviews with firm representatives and innovation consultants embedded in the local region of the respective SMEs concerned with building up knowledge networks and increasing absorptive capacities in regional SMEs. While the questions are derived from previous theoretical and empirical contributions, the interviews comprise open questions and interviewees are asked to explain at length the different innovation and learning processes in their own or their clients' firms. We therefore aim to understand DUI learning at the firm level before identifying measurement options. Following the analysis of the interviews, we derive a number of core processes that are prevalent in the firms in our sample. Using these core processes, we propose measurement options that incorporates our novel results as well as the evidence of previous DUI studies, which can help to structure and facilitate further empirical investigations.

3.2 Sample and interview procedure

In order to investigate how DUI processes take place, we use a criterion-oriented, purposive sample of firms that meet the criterion of innovating (predominantly) in the DUI mode. We used the basic ideal-typical definition of DUI mode learning as defined above to include or exclude potential interview partners at the firm level. This theoretical foreknowledge was used to select typical cases, which is considered helpful for structuring, causal investigation and idea generation (Kepper, 1996, p. 234). In general, this primarily meant excluding firms with formal R&D structures and expenses, while including firms without such structures. Practically, we identified SMEs through an extensive website analysis in the three regions that presented themselves as innovative, had participated in regional innovation contests or had been suggested by regional innovation consultancies. Further, we limited the sample to SMEs with to 1-250 employees. Secondly, we asked interviewees to make suggestions for further interview partners, which met these criteria. Unlike quantitative research, this procedure provides us with a small group of observations rather than a random, extensive sample (Schreier, 2007, p. 233). In addition to a criterion-oriented sample, we applied snowball sampling to acquire similar, related cases of firms, since interference between the cases could be negated (Schreier, 2007, p. 242).

Overall, following this sampling procedure, we interviewed 49 firm representatives (mostly CEOs) who possess detailed knowledge about firm-internal innovation processes and regional networks. Since we are looking for patterns of learning processes applying to SMEs in general, we conducted interviews with firms from different industries and sectors to gain a broader perspective. Table 4 provides an overview of the industry classifications (referring to NACE Rev. 2) for the firms in our sample. The average firm size is 49 employees with a median of 25. Further, we interviewed 32 innovation consultants, who work in and are very familiar with one of the three named case-study regions, know a larger number of companies and can offer an overview of the range of DUI mode innovation processes, particularly regarding firm-external cooperation in their respective regions. Since individual firms often have a limited overview of innovative networks and activities from a regional, cross-sectoral perspective, including the consultants' perspective provides a more holistic picture of regional learning processes. In the result section, quotations from firm representatives are cited using "F", whereas quotations from regional

consultancies are marked with “C”, followed by the interview number. More detailed information on firm- and consultant specifics as well as interview lengths is provided in appendix 7.4 and 7.5.

Industry		**n**
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
Total		49

Table 4. Interview sample according to industry classification (NACE)

At the regional level, we focus on the three German planning regions (“Raumordnungsregionen”[1]) Goettingen, Hanover and East-Thuringia. The regions were chosen for their fairly similar economic structures. All regions include metropolitan areas, which implies organizationally thick regional innovation systems, although with different specializations (Isaksen and Trippl, 2017; Isaksen et al., 2018) and they are characterized by a large number of SMEs. All three regions qualify as being characterized by the ’German Mittelstand’, meaning firms that are rather small, locally embedded without integration into larger corporations or substantial R&D involvement, yet internationally competitive and innovative. Universities and research centers are located in all regions, which would allow local cooperation with the analytical knowledge base. From an international perspective, the support structures of innovation consultants from public or semi-public institutions are fairly similar across regions. Table 5 presents our sample of interviewees by region.

	Goettingen	**Hanover**	**East-Thuringia**	**Total**
n Innovation consultants	10	12	9	32
n Firms	18	15	16	49

Table 5. Interview sample according to regional and functional distribution

After an extensive literature review, we collected core aspects of our research in two interview guidelines (one for firm representatives and one for consultants) and tested the interview guidelines in pilot interviews. This pilot phase was also used to train the interviewer and modify the questions (Mayring, 2002, p. 69). Our interview guidelines are documented in appendix 7.1 and 7.2.

[1] The 96 German planning regions represent functionally integrated spatial units comparable to labor market areas in the United States. Every Federal State of Germany, except from the three city states of Hamburg, Bremen and Berlin, comprises of several planning regions.

We then conducted open, semi-structured interviews (Mayring, 2002, p. 67) between February and October 2018 with 49 firm representatives and 32 regional innovation consultants from business development firms/agencies. Based on different firm-related factors, interviewees are asked to explain in detail how innovation takes place. Questions about formal research include formal connections to knowledge producers, research projects, and the use of patents, among others. Processes and aspects emphasized in previous DUI studies were addressed to investigate their relevance for our interviewees in case they were not mentioned by the interviewees by themselves.

Overall, we aimed to hold in-depth conversations with interviewees and therefore regularly deviated from the formal structure of the interview guideline to react to the interviewee's specific answers. Consequently, the interview guideline was primarily used as a structure to ensure that no aspects were omitted during the interviews, although deviations from its formal structure were intended. The interviews lasted 62 minutes on average, depending on the openness of our interviewees and their level of insight into DUI-relevant processes.

3.3. Qualitative analytical procedure using MaxQDA

While ensuring anonymity, the interviews were recorded on tape or (if an interviewee did not agree) in writing (one case). This standardization facilitates the comparison of the interviews (Mayring, 2002, p. 70). The tapes were transcribed based on the system of Dresing and Pehl (2011) and a qualitative content analysis was conducted, which methodically fragmented the material into controlled units (Mayring, 2010). A theory-driven category system is at the core of our analysis. First, the category system was deductively developed from the two interview guidelines and subsequently it was inductively expanded by categories that the material contains (Mayring, 2002, pp. 114–121). Using MaxQDA, we incrementally reduced the content of the interviews to those statements relevant for our research questions.

To ensure the reliability of the qualitative analysis, we conducted three intercoder comparisons between three researchers. These comparisons were used to define coding rules and eliminate demarcation problems to assure the same coding results among multiple researchers (i.e. the intercoder reliability). The results were saved in code memos (Mayring, 2002, p. 119). Afterwards, the categories were used to summarize and contrast the aspects that the interviewees mentioned. Therefore, we used summary grids to compare specific codes deducing the core DUI mode processes and indications for measuring DUI mode innovation.

4. Results

Our general approach was to analyze the transcripts of our in-depth interviews regarding the categories of doing, using, and interacting as used in the previous literature and in the sense of the seminal theoretical contributions described above. We thus determine whether the core processes discussed in the previous DUI studies can be confirmed as playing an important role in the respective firms' and consultants' understanding of intra-firm innovation dynamics. Thus, our findings were categorized according to the previous contributions to the literature on innovation modes in our coding procedure. Processes or indicators that have been emphasized in previous studies yet are irrelevant within our sample of interviewees are dropped and new processes emphasized by respondents were included. Indicators were adapted to the description and understanding of our interviewees to assure that they are in line with their understanding. We thus derive a list of four dimensions, which are differentiated into fifteen categories. The categories are described in detail in the following chapters. Furthermore, we derive 47 indicators and corresponding items that can be used to measure the respective categories, which are provided in the appendix. For each indicator, we also propose a set of questions that have been used in the literature or can be used – based upon our interviews – to construct questionnaires for further quantitative approaches. Most indicators have been proposed or used in some form in previous studies on innovation measurements: of the 47 items proposed in our study, 43% have been newly formulated, 25% have been adapted, while 32% have been adopted from prior surveys. The indicators and the respective items are documented in appendix 7.3. We also choose to ask for novelties instead of innovation as our interviews showed that respondants often associated innovation with something purely technical. However, if requiered, future surveys can use the word innovation instead of novelty if it better fits the specific research context.

4.1 Learning-by-doing and internal-interaction

Learning-by-doing

In the following, we detail our findings for the dimension of learning-by-doing by proposing the most relevant categories as well as different indicators that can be used to capture the respective category; suggestions for items are documented in appendix 7.3. Table 6 gives exemplary quotations from the interviews and shows the related literature for each category.

Within the dimension of learning-by-doing, our results let us emphasize variables that pronounce knowledge embedded in equipment and employees. With regards to **technology** (category 1), firms either introduce new equipment (indicator 1) or improve their existing equipment (indicator 2). The introduction of new machinery, hardware or software (indicator 3) allows firms across industries to create new products and services, increase their variety of products and services, improve existing products or improve their processes. A common example is an increase in capacities through increased automation (F24). The improvement of existing equipment is described as an everyday task, often as a by-product of new customer requirements to extend the limits of the existing equipment.

Regarding employees, factors such as **training** (category 2), specifically the use of work experience, tacit knowledge and the effective exchange of this knowledge are important. Training is categorized into general training (indicator 4) and specific training (indicator 5) whereby both are conducted to increase firm-internal human capital. General training contributes to an employee's general human-capital whereas specific training is firm-specific and does not increase an employees' productivity at another employer. SMEs offer specific training when employees meet the boundaries of their current expertise or need knowledge about more recent (technological) developments (F7).

According to our findings, a **"trial and error learning"** (category 3) that relies on the application of tacit knowledge are often found at the center of innovation-related activities as employees are able to apply previous solutions to new but similar problems. Thus, the accumulation of tacit knowledge enables long-term problem-solving behavior, which requires scope for trial-and-error learning (indicator 5), the use of experience in trial-and-error learning (indicator 6) as well as creativity in trial-and-error learning (indicator 7). We therefore recommend measuring experience-based knowledge embodied in equipment and employees through a more detailed set of indicators, with a particular focus on the role of employees (F28).

Category	Definition	Verbatim quotes from interviews	Related literature
1. Technology	Firms introduce new machinery in order to keep up with the state of the art. This indicator captures how firms improve their processes through technology introduction or improvement on a regular base.	"*So, we have, for instance a system for electroplating, which is already 15 years old […] in which we have always included new elements. […] We have built those new elements, meaning new parts for the electroplating for ourselves, ok? That means we're building new processes ourselves […] But because the processes evolve so quickly, this is our big challenge, we have to substitute our machines over again, to create new procedures in the production that require a finer approach.*" (F31)	Learning-by-doing takes place, especially in non-R&D-based firms, through technology that is developed in other sectors and embedded in technology (Hippel and Tyre, 1995). Firms that innovate in the DUI mode are often found in LMT sectors and apply the technology developed in other sectors according to their own needs (Robertson and Patel, 2007). A higher degree of new machinery can explain higher firm-level innovativeness (Amara *et al.*, 2008).
2. Training	Captures how often firms use further job training in order to improve production or service-related knowledge of their employees and thus increase the firm's human capital.	"*And I believe that, when people are further qualified, they have benefit in the long term. OK, this is not just their advantage, we as a firm profit as well when I send them to further training. [...] Yes, exactly, that way, new knowledge comes in, that's what I mean. Some works will be done differently, better; they might have taken three hours before, now we can do them more effectively.*" (F24)	General and specific training are important means for firms to increase their human capital (Becker, 1962) and subsequently their innovativeness (Cantner *et al.*, 2014; Apanasovich *et al.*, 2017). An investment in continuous training activities is found to increase firm-level innovativeness (Bauernschuster *et al.*, 2009; Amara *et al.*, 2008).
3. Trial and error learning	This category captures the importance of problem-solving behavior and the application of previous solutions to new problems.	"*Knowledge generation, what do you do to build up some knowledge? You try the same or similar things in a small field. And each time, you learn a bit more. […] Because, he has to get back to the problem. He has to find the analogies between the new and the*	Experienced-based know-how and on-the-job learning are important parts of the DUI mode of innovation (Jensen *et al.*, 2007; Holtskog, 2017; Isaksen and Karlsen, 2010), especially to understand specific market needs and develop customer-

	Firms where employees can experiment and work out new solutions are more innovative.	*old problem. […] I believe it's best if you try to keep the staff for a long time in your firm. That way, the knowledge generation and experience has happened in their heads. […] Yes, and when you have done it for 20 times, you will do it better than the first time […] due to your experience." (F28)*	specific products (Thomä, 2017). A central issue is the role of experience-based know-how for innovation as a part of organizational learning and how it is transferred on a variety of levels (Howells, 1996).

Table 6. Categories, definitions, quotation and contribution to the literature for learning by doing

Internal interacting

In the domain of learning-by-internal-interacting, we propose indicators covering **the importance of informal contacts within the firm** (category 4), **mechanisms of knowledge exchange** (category 5) and **HRM tools** (category 6) that are used by SMEs and fit their description of the respective tools. We suggest that measurement of interaction related to formal mechanisms and procedures witnessed in medium-sized firms is balanced with indicators that emphasize the informal exchange of knowledge and experience, which we find to be more prevalent in smaller firms (F16). Table 7 provides an overview of our categories, gives examples from the interviews and shows related literature.

Learning by internal interaction and processes of knowledge exchange and knowledge production among employees takes place at the firm level and is based on routines and structures. Internal interacting has previously often been identified with measures of 1) formal group compositions (quality circles, multidisciplinary teams, autonomous work groups), 2) structures and tools that foster innovative activities, or 3) idea selection and formal innovation management systems. However, formal mechanisms and tools for knowledge exchange were less prevalent in our interviews. With regards to knowledge exchange, problem-solving and the application of experience-based knowledge is more often based on **informal contacts and relations within the firm** (category 4). More experienced team members and employees share their knowledge through an *informal exchange of knowledge in the workplace* (indicator 8), which is related to good *internal relations among employees within the firm* (indicator 9) and *mutual support among employees* in the domain of problem-solving (indicator 10). Experience is accumulated through a combination of on-the-job or *trial-and error learning* (indicators 5-7) and by *observing more experienced colleagues* (indicator 11) *(F48)*. As firms' knowledge is strongly embedded in their employees, they describe it as crucial that they have low rates of employee turnover to retain innovation-related know-how within their firm (F15, F16, F34). In SMEs, the implementation of HRM practices is less relevant as people are familiar with each other and they more easily have informal contacts and relations within the firm.

More formal **mechanisms of knowledge exchange** (category 5) were previously subsumed under the heading of HRM tools. An example of an HRM tool are regular team meetings like quality circles (or a continuous improvement process (CIP)), which describe regular meetings among team members to discuss quality-related problems and solutions. Quality circles were not mentioned in our interviews, although firms that innovate in the DUI mode nonetheless practiced elements of quality circles, whereby they described the idea behind quality circles without using the term explicitly. This includes r*egular meetings to discuss novelty-related problems* (indicator 12). Many problems, however, are not solved by single employees with a specific specialization but require *knowledge exchange among employees with different tasks* (F16). This was previously described by the term 'integration of functions' which we regard as a technical term for collaboration between employees with different tasks or departments. In addition, an *open communication culture* (indicator 14) can be emphasized as important for continuous improvement and to assure quality (F1, F29).

Finally, we propose to measure the use of **HRM tools, more specifically formal mechanisms of knowledge exchange** (category 6). Structures or departmental barriers that need to be overcome to foster innovative activities are often a problem for larger firms, which have to come up with solutions to become more decentralized and flexible. Here, questions concerning "communication policy that involves the whole organization", "integration of function" or "softened demarcations" are crucial for large enterprises with established hierarchical structures and departments. The previously mentioned HRM tools would often make little sense in SMEs and are therefore seldomly practiced with all its components. For example, this criticism applies to the selection and management of innovative ideas, which is often either handled informally or does not render good results at all in SMEs (F28). In an environment where problem-related solutions can be easily exchanged, the measurement of such formalized mechanisms does not capture the way in which interaction and therefore innovation takes place in firms that rely on the DUI mode of innovation. HRM practices usually only start to exist in medium-sized enterprises where the

flow of knowledge is inhibited; for example, by departmental structures. With regards to HRM tools, we therefore suggest focusing on topics such as the *delegation and degree of autonomy* (indicator 15) instead of HRM tools like quality circles. Furthermore, we suggest capturing the *integration of functions* (indicator 16), for the cases of medium-sized enterprises where departmental barriers exist. Further, the use of *monetary incentives* (indicator 17) as well as single questions that capture the use of *knowledge management (indicator 18)* and *idea management* (indicator 18) are proposed.

Category	Definition	Evidence from interviews	Related literature
4. Informal contacts and relations within the firm	This category captures the importance and presence of informal contacts within the firm. Informal contacts are supposed to speed up knowledge exchange by more easily overcoming department units.	"*And our quality is strengthened by each employee. That means, everyone sees right away where the problem is. And then we do small brainstorming circles or just talk in the hallway or in the office, we talk about those problems and then solve them quickly. We have a high quality quota, that means a low rate of reclamation of under 0,01 percent. (F29)*	Informal processes of learning and knowledge exchange were mentioned by Jensen *et al.* (2007) and highlighted by qualitative studies (Isaksen and Karlsen, 2010; Trippl, 2011; Aslesen and Pettersen, 2017) and parts of it have been measured recently (Rammer *et al.*, 2009; Thomä, 2017; Thomä and Zimmermann, 2019).
5. Mechanisms of knowledge exchange	Captures the way ideas are communicated and exchanged within the firm. A more open communication of ideas is found to lead to a better selection of innovative ideas in the long run.	"*Yes, when our installer, our service engineer comes back […] after each service trip and after each construction of a device, after bigger projects […] we do a round table including installers, sales, mechanical and electrical staff, all departments including R&D and the we discuss everything: what worked and what hasn't worked. So what concerns the production process and purchasing and also where things haven't worked out, right at the device and then this is implemented right away*." (F16)	Regular team meetings, the exchange of knowledge between people with different tasks and an open communication culture are important drivers for innovation. The DUI mode of innovation especially pronounces the importance of interacting such as team meetings (Parrilli and Elola, 2012) and the informal exchange of knowledge Thomä and Zimmermann (2019).
6. Use of HRM tools (formal mechanisms of knowledge exchange)	This category captures structures and mechanisms that are implemented in order to foster the exchange of ideas and development of innovations. Items represent tools of knowledge and innovation management.	"*This so-called knowledge database, we are just working on making them more perfect. We collect the information, e.g. Presentation we had acquired and archive them in the knowledge database. We are just building this up, so you can store all kinds of information. The results from our test series are store there and the whole thing is still being improved. (F40)*	Importance of formal exchange of knowledge increases with firm size (Thomä and Zimmermann, 2019). HRM tools can function as a substitute for R&D in SMEs (Rammer *et al.*, 2009). Previous research on innovation modes emphasized cross-functional integration (both horizontal and vertical) (Apanasovich *et al.*, 2017; Jensen *et al.*, 2007; Parrilli and Elola, 2012), formal mechanisms to collect employee suggestions (Jensen *et al.*, 2007; Nunes and Lopes, 2015; Parrilli and Elola, 2012) and reward systems (Apanasovich *et al.*, 2017; Thomä, 2017).

Table 7. Categories, definitions, quotation and contribution to the literature for learning-by-internal-interacting

4.2 Learning-by-using

Learning-by-using describes processes in which intermediate or end users of a product or process share their experience, modifications or re-designs with the original producer so that the product can be improved, extended or new products are developed (Rosenberg, 1982). Therefore, learning-by-using contains different channels of how a firm interacts with a customer to develop its products or processes. For instance, customers demand a solution that contains either a) a precise order, albeit with somewhat unrealistic or unnecessary specifications or b) no specifications at all. Firms often described an "iterative process" where products are developed or improved in multiple rounds through feedback loops with customers and other actors from within or outside the firm. These feedback loops most often comprise personal interaction and meetings in person. Here, firms need to understand what really drives customer demand to capture an image of what kind of innovative solutions might be required.

Measurements of **cooperation with customers** (category 7) are therefore extended beyond the simple question concerning the importance of customer cooperation. It contains the field of cooperation (indicator 20) and the respective intensity as well as the duration of customer interaction to build up mutual understanding. In addition to these measurements, customer characteristics such as the innovativeness (indicator 22) or its technological know-how (indicator 23) might also play an important role, as more innovative customers ask for more innovative solutions and therefore drive a firm's innovativeness and related learning processes. Finally, the duration of cooperation with customers (indicator 24) does play an important role for innovative effects (C18).

Learning-by-using takes place via different kinds of **contacts with customers** (category 8). Here, we propose a set of measurements that captures different channels for knowledge flows through customer contact. For example, regarding the organizational domain (indicator 25), firm representatives such as CEOs and executives – as representatives of their firm or department – were crucial to maintain contact with customers. The active demand for feedback from customers (indicator 26) as well as the use of customer support (indicator 27) are similarly key factors for innovation with regards to customers. Besides these well-established channels of communication, interaction on social media (indicator 28) becomes more important to source knowledge and ideas from customers (F35).

These customer demands can result in new or improved products and services meeting the customers' **product specifications** (category 9). Through firm-internal communication of these demands and by suggesting possible solutions, the firm's overall product portfolio is altered. Connected to these products and services is a range of indicators that capture the innovativeness of SMEs reflecting their variety of products as well as their properties. The more specific a product, the more often SMEs describe themselves as "problem-solver" and their customer-specific solutions cannot be produced on a large scale (indicator 29). In addition, SMEs have started to offer additional (indicator 30) as well as complimentary products and services (indicator 31) related to their main products. Overall, customer involvement (indicator 32) in the product specifications drives learning and the systematic search for innovative solutions. (F6).

Category	Definition	Evidence from interviews	Related literature
7. Cooperation with customers	This category captures different ways of how customers affect innovativeness. These include cooperation with customers, the intensity of interactions or the way in which customers drive innovativeness through its own innovativeness.	*"And then there is also the case […] that together with the customer this innovation arises. This means that you have developed a product that is in some way well received by the customer. And you successively develop it further together with the customer and then realizes: After three years, looking back, somehow that has changed. But without that it has now been systematically further developed in the sense of: "We have to generate an innovation", an innovation has crept in, so to speak." (C18)*	The impact of intensity of customer interaction and characteristics of the involved customers in different stages of the new product development process is emphasized e.g. by (Gruner and Homburg, 1998); the aspect of mutual understanding by (Mohr and Bitner, 1991).
8. Customer contact	This category captures different ways of customer interaction. It addresses different channels through which customers influence a	*"We have a few fairs […] every year and there we have a decent stand. And that's where we invite the customers or they come to us and discuss it. And that's where the new products are presented." (F35)*	Customer interaction is analysed specifically regarding the role of social media by (Bertschek *et al.*, 2019).

	firm's product and process development.		
9. Product specifications	This category captures the range of a firm's product innovations. Offering additional services to customers further indicates how firms commercialize ideas around their core products.	*Of course, we're driven by global players. In order to not only survive competition, but offer products that customers ask for, we focused on business beside our core competency with regards to innovation. For example, we offer products that are very interesting for our customers, but that no one else offers." (F6)*	Previous studies report that employees find it important to regularly talk to customer to understand their needs (Holtskog, 2017). Firms that innovative according to the DUI model have employees that develop "new products, services or solutions" for their customers. (Isaksen and Karlsen, 2010)

Table 8. Categories, definitions, quotations and contribution to the literature for learning-by-using

4.3 Learning-by-interacting (external)

Learning-by-interacting with external actors was investigated regarding several aspects. In previous studies, firms were often asked to rate the frequency or importance of interaction with an external actor for innovative activities. Measurements include actors such as customers, suppliers, competitors, consultancies and science-related actors. Only few studies investigate industrial associations or trade fairs. According to our categorization, external interaction captures all external, non-science-based actors who are not customers. These include suppliers, competitors, firms from different industries, consultancies, and state organizations, among others. External learning-by-interacting is particularly important for SMEs operating in the DUI mode, as firm-internal knowledge and therefore problem-solving competencies are limited resources. Firms need to access additional knowledge and competencies from an extended network of actors to develop innovations.

For instance, firms rely on **suppliers** (category 10) when developing new products for their customer. *Innovation co-operation* (indicator 33) involves multiples rounds of feedback between customers, the firm itself as well as with suppliers. An example is the material composition of a new product that a customer is demanding. Here, a firm relies on a supplier's core *competence* (indicator 34) or rather knowledge about the material supplied and how different processes might affect its composition. Suppliers can offer advice on how to handle new product development. This in return can require knowledge exchange with another actor – a university, for example – in case a new material for a special application needs to be developed. However, knowledge exchange relies also on the perceived *supplier relationship* (indicator 35) and how interaction is valued.

Interaction with intra-sectoral firms is divided into cooperation with and without competitors. **Cooperation with competitors** (category 11) is challenging and rare, as cooperation is described as a potential risk for the loss of firm-internal know-how. Cooperation with competitors therefore only occurs where it does not risk a firm's specific know-how. Rather interviewees explained that *a competitor relationship* (indicator 36) is based on monitoring them for novelties. However, *competitive pressure* (indicator 37) was mentioned as one part of a motivation for innovation activities.

Intra-sectoral interaction (category 12) takes place with firms from the same sector that are not described as competitors. These are often firms that do not share the same (regional) market and therefore competition is not a problem for both firms. A major benefit of cooperation between these firms is that they share similar problems and an exchange of knowledge can lead to ideas for new product and process developments. Thus, we suggest measuring the *frequency of innovation cooperation* (indicator 38) as well as the perceived importance of an *intra-industry relationship* (indicator 39).

The **interaction of firms between different sectors** (category 13) excludes interaction with competitors by definition. An interaction with firms from other sectors offers access to hidden firm-internal know-how and solutions that firms from the same sector would usually not reveal. These interactions can generate ideas for the implementation of ideas within the firm. In accordance to previous interaction partners the *frequency of innovation cooperation* (indicator 40) as well as the perceived importance of an *extra-industry relationship* (indicator 41) can be measured.

Consultancies and public institutions (category 14) serve several functions: they advise SMEs during *innovation cooperation* (indicator 42) to improve their firm internal innovation processes. However, not all interaction with consultancies there valued as being helpful, thus *relationship to consultancies* (indicator 43) should be measured as well. The interviewees revealed that most often consultancies establish connections with other actors, supply firms with firm-external *funding* (indicator 44) and increase their visibility through hosting *innovation awards* (indicator 45) and network events.

Networks and trade associations (category 15) were frequently used by the interviewed SMEs for *innovation cooperation* (indicator 46). *Trade associations are important* (indicator 47) as they offer SMEs a platform where they can interact with other firms from the same or different industries to discuss common problems and access new knowledge about market developments and therefore possible directions for future innovations. These could extend beyond regional networks to extra-regional or even international networks. Trade fairs are one particular example that is deemed important by SMEs as they offered access to customers, suppliers, competitors and other firms at the same time.

Our set of measurements contains all previously-mentioned external DUI actors and enables capturing these interactions in a more adequate manner for SMEs.

Category	Definition	Evidence from interviews	Related literature
10. Cooperation with suppliers	This category captures different ways of how suppliers influence a firm's innovative activities. Suppliers are important due to their competencies, specific know-how or sharing knowledge about new (technological) developments.	"*What is the suppliers' influence on your firm?" "Well, first of all through new and innovative products and applications of the respective products. That is the main aspect*." (F30)	Interaction with suppliers mentioned by Jensen *et al.* (2007) and Isaksen and Trippl (2017).
11. Intra-sectoral firms (including competitors)	This category captures the importance of competitors for a firm's innovative activities. It includes observing competitors and the perceived pressure to develop own products.	"*Our huge advantage is that we are allowed to repair all of our competitors' products. […] So we know the errors and issues with other products that we don't want to have on our products.*" (F29)	Contrary to Jensen *et al.* (2007), competitor collaboration was less mentioned as being relevant for DUI innovation processes. Fitjar and Rodríguez-Pose (2013) showed that collaboration with competitors had even a detrimental effect on innovation activities. Thus, competitors seem to play a different role than other interacting partners.
12. Intra-sectoral firms (excluding competitors)	This category captures the importance of firms from the same sector for a firm's innovative activities. This excludes competitors. For example, firms might not compete for the same regional market but share similar innovation-related problems	"*Extra-regional is not a problem at all. So you can choose someone over the internet, who might be much smaller than we are who does everything on his own: selling, baking or bakers with 140 subsidiaries. You just get different views quite simply and can profit immensely.*" (F5)	Cooperation with intra-sectoral firms that are no competitors, were not mentioned in the DUI literature before.

	where an exchange of knowledge or cooperation is beneficial.		
13. Extra-sectoral firms	This category captures the importance of firms from other sectors for a firm's innovative activities. Firms from other sectors are a source of knowledge about technology and new developments as sharing knowledge about core competencies or processes isn't life threatening for a firm.	"*Also, less competitors, but rather firms working in other domains that are interesting for us and bring together competencies to create innovation. [Q: so you mean across industries?] Yes, exactly. I think more important than working together with your competitor is to create a network that has different competencies available to your firm.*" (F19)	Cooperation with extra-sectoral firms were not mentioned in the DUI literature before. However, it is in line with studies of combinatorial knowledge bases. (Bennat and Sternberg, 2019) argue that interactive learning processes tend to cross sectors, reaching beyond qualifications.
14. Consultancies and public institutions	This category captures the importance of (public and private) consultancies for a firm. They might provide new information and contacts, organize exchange events or advice with regards to financing.	"*We also have an external consultant, who has counseled me in terms of development and has a strong dialogue with our developers. We basically have a regional innovation cycle, where we discuss these developments. And there, I would argue, we start to be innovative, ok? However, we don't plan innovations there in a traditional sense.*" (F8)	Interaction with consultancies were not mentioned in die DUI literature before. However, regional policymakers are engaged in promoting and supporting interactive learning, and hence regional cooperation (Martin *et al.*, 2011). It is in line with the Regional Innovation System approach, highlighting the importance of geographic proximity for knowledge exchange and learning dynamics, as well as its regional governance structure (Asheim *et al.*, 2016).
15. Trade associations and networks	This category captures different aspects of the role of industry associations and trade fairs. This might include the sharing of resources, knowledge or tackling common industry-specific problems.	"*And the main part is that we are very active in brewers' association and work with other firms in different circles on different topics. And of course, visits to fairs […]. We don't leave it to chance that these technologies reach us at some point.*" (F7)	Using informal settings to acquire new knowledge for example at trade fairs has been explained as one important source for knowledge relevant for innovation activities (Isaksen and Trippl, 2017).

Table 9. Categories, definitions, quotations and contribution to the literature for learning by (external) interacting

5. Discussion

Overall, the dimensions and processes constituting the DUI mode are intertwined in multiple ways. For instance, a firm develops its competencies over time through learning-by-doing, depending on its previous path. Components of learning-by-doing include experience and tacit knowledge. However, the direction and further development of theses competencies is strongly influenced by – for example – customer demands, which guide a firm through multiple rounds of product or service developments into a certain direction. Driven by customer demand, this firm-internal accumulation of knowledge in return requires access to an external network of actors, which allows a firm to access new knowledge. One example might include specific training for innovation-related activities, while another is the introduction of new machinery from suppliers to meet ever-increasing customer demands for variability. Another example is the interaction between a customer's demand and a firm's competencies. Firms often mention that customers come up with certain specifications that are rather unnecessary or impossible to comply with. Firms then explain to a customer her requirements more specifically from their perspective, which can be met through several possible solutions that the customer is, ex ante, not aware of. This is an example of how a firm's internal competency – based on (historically-developed) tacit knowledge – interacts with learning-by-using in a firm-customer interaction. A solution requires several feedback loops between the customer, the firm representative as well as firm-internal actors who understand customer demand and product-specific details.

Thus, DUI processes are strongly interconnected at the firm level, whereby no single factor can and should be identified as the main driver of innovative performance. When applied in quantitative studies, our set of indicators enables a more encompassing and detailed investigation of the combination of different drivers of innovative performance and different clusters of DUI firms with specific manifestations of the respective set of processes. Our contribution is to map out a system of indicators along theoretically-derived dimensions that – we would suggest – captures the overall system of DUI learning in SMEs. Figure 2 shows the fifteen dimensions along the relevant actors. Our suggestions for measuring the related processes are documented in appendix 7.3.

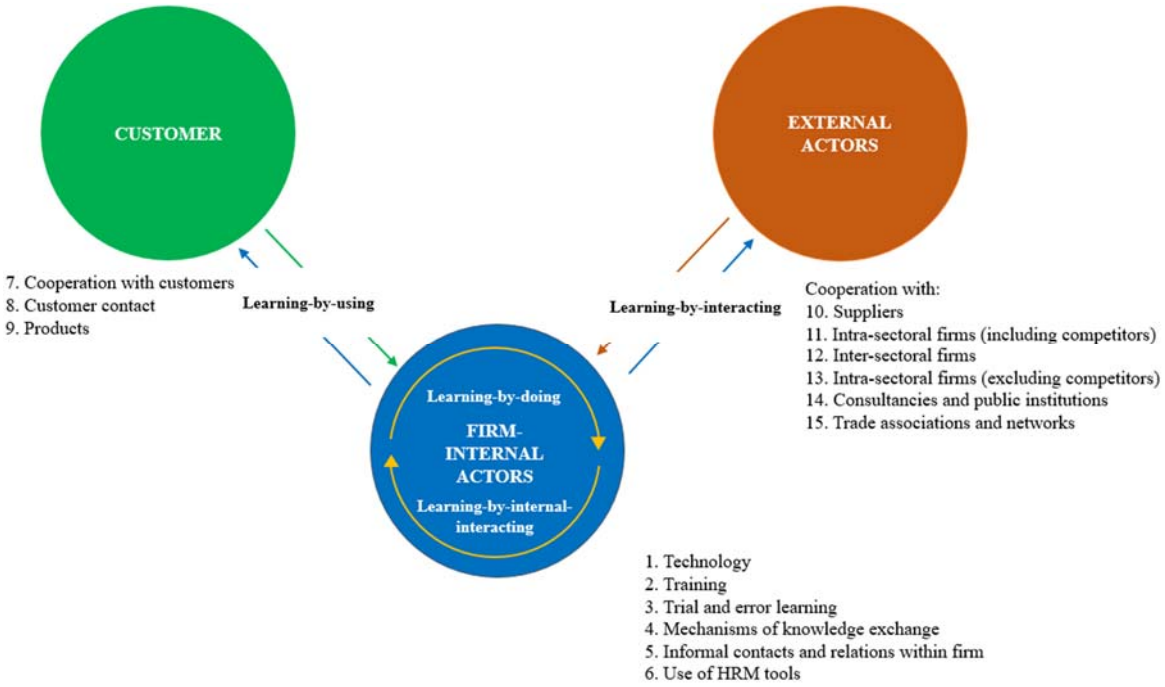

Figure 2. DUI dimensions, respective learning processes and measurement categories

Future quantitative studies should identify types of DUI firms and patterns of learning in relation to the overall innovative or business performance. Furthermore, core indicators for the respective types of firms and patterns should be identified that capture their level of DUI activity. This is a markedly different approach than previous empirical contributions on the DUI mode, which have relied upon individual factors or industries that are considered characteristic of DUI learning. We suggest that future empirical research should take a step back and first attempt to show quantitative patterns of DUI learning for different industries, firm sizes and innovative success and then derive proxies for the respective types of firms. Our qualitative approach should be read as a suggestion for different indicators that can be used to attempt this initial broad quantitative approach to DUI learning. While qualitative studies obviously cannot replace the quantitative investigations (and vice versa), we argue that they play an important role in informing future surveys of the variety of different processes at play in DUI firms.

6. Conclusion

This study has investigated the DUI mode of innovation and its underlying learning processes. To this end, we ran a large series of in-depth interviews with firm representatives and innovation consultants to understand the key DUI processes, derive indicators and develop items that more comprehensively capture DUI innovativeness. We therefore suggest a list of fifteen key processes that were instrumental in making and keeping firms in our sample innovative. Overall, we suggest that our qualitative approach enables us to argue convincingly, which previously used indicators play a role in firms' learning routines, add further indicators and suggest items that can adequately capture those processes. The newly derived set of indicators and the novel items are geared towards future quantitative investigations that can better explain the innovative performance and specifics of DUI firms.

While our sample of German 'Mittelstand'-SMEs have been primarily chosen as exemplary firms exhibiting DUI processes and innovativeness saliently, our results enable us to derive SME-specific policy and research implications. Based upon our interviews, we argue that future surveys on DUI mode learning need to devote more attention to the characteristics of SMEs as an important addressee of policy efforts to foster low-level innovative performance. We find that in the SME segment, most formal ways of internal interaction emphasized by prior DUI studies do not play an important role for innovation-related activities. We suggest that an issue in the current literature of innovation modes is its presupposition that smaller firms need to compensate R&D with HRM-related management practices in order to become more innovative – the underlying assumption being that small firms essentially face the same problems as large firms, namely a lack of integration of functions, a high degree of anonymity and therefore a lack of quick fixes as well as departmental structures that inhibit knowledge exchange. However, these problems do not exist in SMEs, simply because they have not developed the structures that become a barrier to knowledge exchange in larger enterprises in the first place. Some measurements of formal structures might correctly display processes in smaller enterprises (quality circles), although firms often either lack the resources (in terms of time and money) to establish such structures or simply are not familiar with the terms used in the literature. Thus, these kinds of constructs should be measured through multiple items that more clearly convey their underlying principle, instead of asking about the more general term used in larger firms and the scientific discussion. This might reduce comparability with larger firms using established tools for innovation management yet increase a survey's ability to convey information on the occurrence and relevance of actual processes in smaller firms. This also relates to semantical issues connected to the use of the term "innovation" in surveys addressing SMEs. Based upon our interviews, we argue that the extensive use of this term can bias our understanding of firms' actual processes. At least in the German case, their understanding of innovation is essentially influenced by its mainstream semantical use, i.e. radical innovations. The natural reaction of an – by all definitions – incrementally innovative and successful SME is to fully reject the term "innovative" for its actions and often go by the more modest "novelties for the customer". Thus, the development of items in surveys – if DUI innovation is addressed – needs to consider the firm's assumed definition of innovation. Consequently, our overarching suggestion for approaching SME innovativeness is to address the underlying principles and refrain from using general terms that may be misunderstood by the target audience, which might substantially bias a survey's results.

Promoting innovation through innovation policy is necessarily connected to understand and measure the key characteristics driving innovations. Therefore, our approach should be read in the context of research aiming to widen a narrow definition and measurement of innovation and foster a broader set of policy mechanisms to increase innovative performance in firms without formal R&D structures, most often SMEs. However, this requires quantitative work to determine regional or sectoral clusters of DUI firms and their particular characteristics, which can then be used to design policies more specifically supporting their innovative performance. Our qualitative investigation, the resulting processes as well as measurement suggestions can be used as a methodological basis for such approaches.

Acknowledgments

Our special thanks go to the research team as well as the interviewees, for taking their time for our interviews. Furthermore, we would like to thank all our other colleagues for their valuable comments on earlier drafts of this manuscript.

This work was supported by the Federal Ministry of Education and Research under Grant 16IFI005.

The qualitative data are not publicly available due to restrictions. They containing information that could compromise the privacy of research participants.

7. Appendix

7.1 Interview guideline for firm representatives

Category	Question
1. Firm specifics	Interviewee demographics (Position, time spend in the firm, previous positions in the firm, education); Firm demographics (Founding year, legal status, chamber association, number of employees, revenue, sector, main product); Market environment (position in the value chain, main customers, geography of sales)
2. New innovations within the last 3 years	Which novelties have you produced within the last three years (product, process, social, marketing, innovation)?
3. The role of formal knowledge	Do you conduct formal research? Do you cooperate with universities (in research projects)? What is the role of high-skilled labor for your firm? Do you use patents?
4. Process improvements	Do you achieve cost reduction or quality improvements over time? How? (Learning curve effects) Have you introduced new machines? How did learning occur? Which employees are important for improvements?
5. Importance of implicit knowledge and employee skills	How is knowledge produced at the firm level? Are there individual employees who possess key knowledge? How to do you preserve tacit knowledge competencies within the firm?
6. Knowledge exchange within the firm	How do you exchange knowledge and experience within the firm regarding your production? Do you use heterogeneous teams?
7. Customer relations and exchange	How do customers influence your product innovations or your product improvements? Which channels do you use to communicate with your customer? Do you customize products according to customer wishes? Do you use new deployments of your product developed by your customer?
8. Competitor relations and exchange	Do you exchange ideas and resources with your competitors? How do competitors influence your innovative capacity? How do you communicate with competitors?
9. Other actors influence on innovations	Do other actors like suppliers, banks and governmental institutions influence your innovative capacity? How do you exchange with other actors?
10. The role of digitalization	How relevant is digitalization for your firm? What are barriers to more innovation? Is digitalization influencing innovations within your firm? How?
11. Expertise change and unlearning	Have the required competencies changed in your firm within the last ten years? How have work routines changed? Have you actively unlearned competencies? Has this influenced your innovative capacity?

7.2 Interview guideline for regional innovation consultants

Category	Sub-question
1. Job description/task/role	What does your job description say about promoting innovation in SMEs? (short)
2. Meaning of innovation	How do you define innovation? How do your clients define innovation?
3. Innovative behavior and innovation without R&D	How do SMEs innovate without formal R&D? What processes in SMEs foster innovation?
4. Regional aspect of innovation	Which particular factors favor the capability to innovate in SMEs in our region? Are there regionally-specific factors that influence the innovation capability of SMEs in our region?
5. Importance of the relation to other firms	How does cooperation with other firms or organizations influence innovation capabilities of SMEs?
6. Importance of experience-based-knowledge	What role does experience-based knowledge play in SMEs' innovation processes?
7. Role of external sources in general	What role does different knowledge (for example from universities, other industries or the creative sector) play in SMEs' innovation processes?
8. Economic policy aspects	Which kind of challenges do you face for regional innovation policy to increase innovation activities in SMEs in our region?

7.3 List of Dimensions, categories, definitions, indicators and potential items

Dimension	Category	Definition	Indicator	Item (*taken from previous studies, ** adapted from previous studies, ***new)	Source of item
Learning-by-doing and learning-by-interacting (internal)	1. Technology	Firms introduce new machinery in order to keep up with the state of the art. This indicator captures how firms improve their processes through technology improvement on a regular base.	1. (New) technology introduction	*How important was the introduction of new machinery, hardware and software for the introduction of new or improved: a) Products or services b) Manufacturing processes (including digital processes) c) Organizational structures (including digital structures)	Derived from the CIS panel; acquisition of advanced machinery, equipment, software and buildings to be used for new or significantly improved products or processes Rammer et al. (2009); Marzucchi and Montresor (2017)
			2. (Current) technology improvement	***How important was the continuous improvement of machinery, hardware and software for the introduction of new or improved: a) Products or services b) Manufacturing processes (including digital processes) c) Organizational structures (including digital structures)	Own elaboration
	2. Training	Captures how often firms use workshops in order to improve production or service-related knowledge of their employees and thus increase the firm's human capital.	3. Training (general qualification)	**How important is general training for your novelties?	Apanasovich et al. (2017); Rammer et al. (2009)
			4. Training (specific aspects)	**How important is specific training for your novelties?	Apanasovich et al. (2017);

				Rammer et al. (2009)
3. Failure-tolerant culture	This category captures the importance of problem-solving behavior and the application of previous solutions to new problems. Firms where employees can experiment and work out new solutions are more innovative.	5. Trial-and-error learning: scope for trial-and-error learning	*How important is scope for trial-and-error for your novelties?	Thomä (2017); Herstad and Brekke (2012)
		6. Trial-and-error learning: Use of experience	***How important is the application of previous solutions to new problems for your novelties?	Own elaboration
		7. Trial-and-error learning: creativity	***How important is working on problems without a predefined solution for your novelties?	Thomä (2017)
4. Informal contacts and relations within the firm	This category captures the importance and presence of informal contacts within the firm. Informal contacts are supposed to speed up knowledge exchange by more easily overcoming department units.	8. Maintaining informal contacts within the firm	*How important is maintaining informal contacts within the firm for your novelties?	Thomä and Zimmermann (2019); Rammer et al. (2009)
		9. Maintaining good relations within the firm	***How important are good relations among your employees for your novelties?	Own elaboration
		10. Mutual support	**How important is mutual support within the firm for your novelties?	Thomä and Zimmermann (2019); Rammer et al. (2009)
		11. Learning by observing	***How important is the improvement of competencies through observing others in your firm for your novelties?	Own elaboration
5. Mechanisms of knowledge exchange	Captures the way ideas are communicated and exchanged within the firm. A more open communication of ideas is found	12. Regular team meetings	**How important are regular meetings of your employees in order to solve novelty-related problems?	Apanasovich et al. (2017); Parrilli and Elola (2012);

		to lead to a better selection of innovative ideas in the long run.			Thomä and Zimmermann (2019); Rammer et al. (2009)
			13. Knowledge exchange among employees with different tasks	**How important is the exchange of knowledge between employees with different tasks for your novelties?	Jensen et al. (2007); Nunes and Lopes (2015); Thomä (2017)
			14. Open communication culture	*How important is the open communication of ideas for your novelties?	Thomä and Zimmermann (2019) Rammer et al. (2009)
	6. Use of HRM tools (formal mechanisms of knowledge exchange)	This category captures structures and mechanisms that are implemented in order to foster the exchange of ideas and development of innovations. Most items represent tools of innovation management, but are adapted to fit the structure and descriptions of SMEs.	15. Delegation and degree of autonomy	**How important is the delegation of tasks for your novelties?	Apanasovich et al. (2017) Parrilli and Elola (2012) Rammer et al. (2009)
			16. Integration of functions	*How important is the integration of functions for your novelties?	Jensen et al. (2007) Nunes and Lopes (2015)
			17. Monetary incentives	**How important are monetary incentives for your novelties?	Apanasovich et al. (2017) Rammer et al. (2009)
			18. Knowledge management	***How important is a system or program to codify knowledge for your novelties?	Own elaboration
			19. Idea management	*How important is a formalized idea management for the selection of ideas for your novelties?	Parrilli and Elola (2012)
Learning-by-using	7. Cooperation with customers	This category captures different ways of how customers affect innovativeness. These include cooperation with customers, the intensity of interactions or the way in which customers drive	20. Thematic field of cooperation with customers	*How important is the exchange with customers for the introduction of new or improved: a) Products or services?	Chen et al. (2011); Fitjar and Rodríguez-Pose (2013); Fu et al. (2013); González-Pernía et al. (2015);

	innovativeness through its own innovativeness.		b) Production processes (including digital)? c) Organizational structures (including digital)?	Nunes and Lopes (2015); Apanasovich et al. (2016); Apanasovich et al. (2017); (Gruner and Homburg, 1998)
		21. Intensity of customer cooperation/interaction	*How important is your exchange with customers for the development of new or improved: a) Products or services? b) Production processes (including digital)? c) Organizational structures?	Jensen et al. (2007); Thomä and Zimmermann (2019); (Gruner and Homburg, 1998)
		22. Customer innovativeness	*How inventive are the customers you interact with?	(Gruner and Homburg, 1998)
		23. Customer technological know-how	*How developed is the technological know-how of the customers you interact with?	(Gruner and Homburg, 1998)
		24. Duration of customer contact	***How long did the customer relationship last before you entered into a cooperation/a more intensive exchange with the customer?	Own elaboration
8. Customer contact	This category captures different ways of customer interaction. It addresses different channels through which customers influence a firm's product and process development.	25. Organizational area of cooperation with customers	***How important is the exchange with customers (beyond a normal business relationship) in the following areas: (a) Procurement? (b) Sales? (c) In connection with reclaims?	Own elaboration

			(d) Production? (e) In connection with trade fairs?	
		26. Active feedback	***Do you ask for active feedback from customers for the development of new or improved: a) Products or services b) manufacturing processes (also digital processes) c) Organizational structures (also digital structures)	Own elaboration
		27. Use of customer support	***Do you use customer support to get feedback and suggestions for improvements for the development of new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)?	Own elaboration
		28. Use of social media	*Do you use social media channels to get suggestions for improvements for your products/services?	Bertschek *et al.* (2019)
9. Products	This category captures the range of a firm's product innovations. SMEs are often specialized suppliers and problem solvers for large-scale enterprises. Offering additional services to customers further indicates how firms commercialize ideas around their core products.	29. Customized products	***Are your products mainly customer-specific and cannot be sold directly to other customers?	Own elaboration
		30. Additional products and services	***Do you offer additional services directly related to your core product/service?	Own elaboration

			31. Complementary products or services	***Do you offer complementary products/services around your core product?	Own elaboration
			32. Customer involvement	***Do you involve your three most important customers in the development of new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)?	Own elaboration
Learning-by-interacting (external)	10. Cooperation with suppliers	This category captures different ways of how suppliers influence a firm's innovative activities. Suppliers are important due to their competencies, specific know-how or sharing knowledge about new (technological) developments.	33. Innovation cooperation (frequency)	**How often do you integrate suppliers in the introduction of new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)>	Thomä and Zimmermann (2019)
			34. Competences	**To what extent did the exchange with suppliers lead to an improvement of your in-house competencies?	Herstad and Brekke (2012)
			35. Supplier relationship	*How important is the exchange with suppliers for the introduction of new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)?	Chen et al. (2011); González-Pernía et al. (2015); Apanasovich et al. (2016); Parrilli and Heras (2016); Apanasovich et al. (2017); Marzucchi and Montresor (2017)
	11. Intra-sectoral firms (including competitors)	This category captures the importance of competitors for a firm's innovative activities. This	36. Competitor relationship	**How important is monitoring competitors for novelties for your firm?	Chen et al. (2011); Fitjar and Rodríguez-Pose (2013);

	include (formal) collaborations, constant pressure to develop own products or access to new knowledge through hiring employees.			González-Pernía et al. (2015) Nunes and Lopes (2015); Parrilli and Heras (2016); Apanasovich et al. (2017); Marzucchi and Montresor (2017)
		37. Competitive pressure	***To what extent is the pressure for your firm to produce novelties increased by competitors?	Own elaboration
12. Intra-sectoral firms (excluding competitors)	This category captures the importance of firms from the same sector for a firm's innovative activities. This excludes competitors. For example, firms might not compete for the same regional market but share similar innovation-related problems where an exchange of knowledge or cooperation is beneficial.	38. Innovation cooperation (frequency)	***How often do you interact with companies in the same industry that are not competitors when introducing new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)?	Own elaboration
		39. Intra-sectoral relationship	***How important are novelties by companies in the same sector that are not competitors for the introduction of new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)?	Own elaboration
13. Extra-sectoral firms	This category captures the importance of firms from other	40. Innovation cooperation (frequency)	**How often do you interact with companies from other	Chen et al. (2011)

	sectors for a firm's innovative activities. Firms from other sectors are a source of knowledge about technology and new developments.		industries when introducing new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)?	
		41. Extra-industry relationship	***How important are innovations from other industries in your company for the introduction of new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)?	Own elaboration
14. Consultancies and public institutions	This category captures the importance of (public) consultancies for a firm. They might provide new information and contacts, organize exchange events or advice with regards to financing.	42. Innovation cooperation (frequency)	**How often do you interact with business/innovation consultants in the context of introducing new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)?	Fitjar and Rodríguez-Pose (2013); González-Pernía et al. (2015); Nunes and Lopes (2015); Thomä and Zimmermann (2019)
		43. Relation to consultancies	*How important are business/innovation consultants for the introduction of new or improved: a) Products or services? b) Manufacturing processes (also digital processes)? c) Organizational structures (also digital structures)?	Fitjar and Rodríguez-Pose (2013); González-Pernía et al. (2015); Nunes and Lopes (2015); Thomä and Zimmermann (2019)
		44. Financing	***How important is public funding for novelties in your company?	Own elaboration

		45. Importance of innovation awards	***How important are innovation awards for producing novelties in your company?	Own elaboration
15. Trade associations and networks	This category captures different aspects of the role of industry associations. This might include the sharing of resources, knowledge or tackling common industry-specific problems.	46. Innovation cooperation (frequency)	*How often do you use the following networks for novelties in your firm: a) Professional associations? b) Regional networks? c) Supra-regional networks? d) Trade fairs?	Marzucchi and Montresor (2017); Thomä and Zimmermann (2019); Nunes and Lopes (2015)
		47. Importance of network relations	*How important are the following networks for novelties in your firm: a) Professional associations? b) Regional networks? c)Supra-regional networks? d)Trade fairs?	Marzucchi and Montresor (2017); Thomä and Zimmermann (2019); Nunes and Lopes (2015)

7.4 Information on firm interviews

Number	Position of interviewee	Region	Interview length (minutes)	NACE Code	Aggregation of sectors
F1	CEO	Goettingen	104	M - Professional, scientific and technical activities	Knowledge-intensive services (KIS)
F2	CEO	Goettingen	66	B - Mining and quarrying	Other sectors (A,B and F)
F 3	Executive	Goettingen	71	F - Construction	Other sectors (A,B and F)
F 4	CEO	Goettingen	96	J - Information and communication	Knowledge-intensive services (KIS)
F 5	CEO	Goettingen	73	CA - Manufacture of food products, beverages and tobacco produc	Low-technology manufacturing
F 6	CEO	Goettingen	67	CM - Other manufacturing, and repair and installation of machin	Medium-high-technology manufacturing
F 7	Executive	Goettingen	64	CA - Manufacture of food products, beverages and tobacco produc	Low-technology manufacturing
F 8	CEO	Goettingen	71	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 9	CEO	Goettingen	76	J - Information and communication	Knowledge-intensive services (KIS)
F 10	CEO	Goettingen	63	G - Wholesale and retail trade; repair of motor vehicles and mo	Less knowledge-intensive services (LKIS)
F 11	Executive	Goettingen	40	CH - Manufacture of basic metals and fabricated metal products,	Medium-low-technology manufacturing
F 12	CEO	Goettingen	64	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 13	CEO	Goettingen	78	G - Wholesale and retail trade; repair of motor vehicles and mo	Less knowledge-intensive services (LKIS)
F 14	CEO	Goettingen	69	M - Professional, scientific and technical activities	Knowledge-intensive services (KIS)
F 15	CEO	Goettingen	80	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 16	CEO	Goettingen	84	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 17	CEO	Hanover	60	S - Other service activities	Less knowledge-intensive services (LKIS)
F 18	Development	Hanover	70	F - Construction	Other sectors (A,B and F)
F 19	CEO	Hanover	64	M - Professional, scientific and technical activities	Knowledge-intensive services (KIS)
F 20	CEO	Hanover	55	J - Information and communication	Knowledge-intensive services (KIS)
F 21	CEO	Hanover	70	J - Information and communication	Knowledge-intensive services (KIS)
F 22	CEO	Hanover	33	Q - Human health and social work activities	Knowledge-intensive services (KIS)
F 23	CEO	Hanover	85	CE - Manufacture of chemicals and chemical products	Medium-high-technology manufacturing
F 24	CEO	Hanover	64	CH - Manufacture of basic metals and fabricated metal products,	Medium-low-technology manufacturing
F 25	CEO	Hanover	44	CK - Manufacture of machinery and equipment n.e.c.	Medium-high-technology manufacturing
F 26	CEO	Hanover	90	CK - Manufacture of machinery and equipment n.e.c.	Medium-high-technology manufacturing
F 27	CEO	Hanover	40	A - Agriculture, forestry and fishing	Other sectors (A,B and F)
F 28	CEO	Jena	92	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 29	CEO	Hanover	87	CK - Manufacture of machinery and equipment n.e.c.	Medium-high-technology manufacturing
F 30	CEO		58	M - Professional, scientific and technical activities	Knowledge-intensive services (KIS)
F 31	CEO	Hanover	42	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing

F 32	CEO	Hanover	66	J - Information and communication	Knowledge-intensive services (KIS)
F 33	CEO	Hanover	74	G - Wholesale and retail trade; repair of motor vehicles and mo	Less knowledge-intensive services (LKIS)
F 34	CEO	Jena	150	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 35	CEO	Jena	67	N - Administrative and support service activities	Less knowledge-intensive services (LKIS)
F 36	CEO	Jena	31	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 37	CEO	Goettingen	75	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 38	CEO	Jena	29	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 39	CEO	Jena	39	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 40	CEO	Jena	35	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 41	CEO	Jena	17	CH - Manufacture of basic metals and fabricated metal products,	Medium-low-technology manufacturing
F 42	CEO	Jena	89	CA - Manufacture of food products, beverages and tobacco produc	Low-technology manufacturing
F 43	CEO	Jena	26	G - Wholesale and retail trade; repair of motor vehicles and mo	Less knowledge-intensive services (LKIS)
F 44	CEO	Jena	49	CH - Manufacture of basic metals and fabricated metal products,	Medium-low-technology manufacturing
F 45	CEO	Jena	32	CH - Manufacture of basic metals and fabricated metal products,	Medium-low-technology manufacturing
F 46	CEO	Jena	12	J - Information and communication	Knowledge-intensive services (KIS)
F 47	Executive	Jena	70	CH - Manufacture of basic metals and fabricated metal products,	Medium-low-technology manufacturing
F 48	CEO	Jena	89	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing
F 49	Executive	Jena	109	CI - Manufacture of computer, electronic and optical products	High-technology manufacturing

7.5 Information on regional consultant interviews

Number	Organization	Region	Interview length (minutes)
C1	Public	Goettingen	75
C2	Public	Goettingen	74
C3	Privat	Goettingen	77
C4	Privat	Goettingen	93
C5	Privat	Goettingen	68
C6	Privat	Goettingen	143
C7	Public	Goettingen	71
C8	Privat	Goettingen	88
C9	Public	Goettingen	94
C10	Public	Goettingen	84
C11	Public	Hanover	72
C12	Public	Hanover	73
C13	Public	Hanover	91
C14	Public	Hanover	55
C15	Privat	Hanover	80
C16	Public	Hanover	77
C17	Privat	Hanover	80
C18	Public	Hanover	69
C19	Privat	Hanover	66
C20	Public	Hanover	65
C21	Public	Hanover	54
C22	Public	Hanover	n/a no permission to record interview
C23	Public	Jena	91
C24	Public	Jena	49
C25	Public	Jena	85
C26	Public	Jena	40
C27	Public	Jena	66
C28	Public	Jena	57
C29	Privat	Jena	62
C30	Public	Jena	81
C31	Privat	Jena	73
C32	Public	Goettingen	60

8. References

Abramovitz, M. (1956), “Resource and output trends in the United States since 1870”, in Resource and output trends in the United States since 1870, NBER, pp. 1–23.

Amara, N., Landry, R., Becheikh, N. and Ouimet, M. (2008), “Learning and novelty of innovation in established manufacturing SMEs”, Technovation, Vol. 28 No. 7, pp. 450–463.

Apanasovich, N. (2016a), “Modes of Innovation. A Grounded Meta-Analysis”, Journal of the Knowledge Economy, Vol. 7 No. 3, pp. 720–737.

Apanasovich, N., Alcalde Heras, H. and Parrilli, M.D. (2016b), “The impact of business innovation modes on SME innovation performance in post-Soviet transition economies. The case of Belarus”, Technovation, 57-58, pp. 30–40.

Apanasovich, N., Alcalde-Heras, H. and Parrilli, M.D. (2017), “A new approach to business innovation modes: the ‘Research, Technology and Human Resource Management (RTH) model’ in the ICT sector in Belarus”, European Planning Studies, Vol. 25 No. 11, pp. 1976–2000.

Arrow, K.J. (1962), “The Economic Implications of Learning by Doing”, The Review of Economic Studies, Vol. 29 No. 3, p. 155.

Asheim, B., Grillitsch, M. and Trippl, M. (2016), “Regional Innovation Systems:. Past-Presence-Future”, in Carrincazeaux, C., Doloreux, D. and Shearmur, R. (Eds.), Handbook on the Geographies of Innovation, Edward Elgar Publishing, Cheltenham, pp. 45–62.

Asheim, B.T., Boschma, R. and Cooke, P. (2011), “Constructing Regional Advantage. Platform Policies Based on Related Variety and Differentiated Knowledge Bases”, Regional Studies, Vol. 45 No. 7, pp. 893–904.

Aslesen, H.W., Isaksen, A. and Karlsen, J. (2012), “Modes of Innovation and Differentiated Responses to Globalisation—A Case Study of Innovation Modes in the Agder Region, Norway”, Journal of the Knowledge Economy, Vol. 3 No. 4, pp. 389–405.

Aslesen, H.W. and Pettersen, I.B. (2017), “Entrepreneurial firms in STI and DUI mode clusters. Do they need differentiated cluster facilitation?”, European Planning Studies, Vol. 25 No. 6, pp. 904–922.

Bauernschuster, S., Falck, O. and Heblich, S. (2009), “Training and Innovation”, Journal of Human Capital, Vol. 3 No. 4, pp. 323–353.

Becker, G.S. (1962), “Investment in human capital: A theoretical analysis”, The Quarterly Journal of Economics, Vol. 70 No. 5, Part 2, pp. 9–49.

Bennat, T. and Sternberg, r. (2019), “Knowledge bases in German regions: what hinders combinatorial knowledge dynamics and how regional innovation policies may help”, European Planning Studies, Vol. 27, pp. 1–21.

Bertschek, I., Polder, M. and Schulte, P. (2019), “ICT and resilience in times of crisis: evidence from cross-country micro moments data”, Economics of Innovation and New Technology, Vol. 28 No. 8, pp. 759–774.

Boschma, R. (2005), “Proximity and Innovation. A Critical Assessment”, Regional Studies, Vol. 39 No. 1, pp. 61–74.

Cantner, U., Gerstlberger, W. and Roy, I. (2014), Works councils, training activities and innovation: A study of German firms, Jena Economic Research Papers, available at: https://www.econstor.eu/bitstream/10419/98440/1/780578392.pdf.

Chen, J., Chen, Y. and Vanhaverbeke, W. (2011), “The influence of scope, depth, and orientation of external technology sources on the innovative performance of Chinese firms”, Technovation, Vol. 31 No. 8, pp. 362–373.

Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. (1988), Technical Change and Economic Theory, Laboratory of Economics and Management (LEM), Sant'Anna School of Advanced Studies, Pisa, Italy.

Dresing, T. and Pehl, T. (2011), “Praxisbuch Transkription”, Regelsysteme, Software und praktische Anleitungen für qualitative ForscherInnen, Vol. 2.

Eisenhardt, K.M. (1989), “Building Theories from Case Study Research”, Academy of Management Review, Vol. 14 No. 4, pp. 532–550.

Eisenhardt, K.M. and Graebner, M.E. (2007), “Theory Building From Cases: Opportunities And Challenges”, Academy of Management Journal, Vol. 50 No. 1, pp. 25–32.

Fitjar, R.D. and Rodríguez-Pose, A. (2013), “Firm collaboration and modes of innovation in Norway”, Research policy policy, management and economic studies of science, technology and innovation, Vol. 42 No. 1, pp. 128–138.

Fu, W., Revilla Diez, J. and Schiller, D. (2013), “Interactive learning, informal networks and innovation: Evidence from electronics firm survey in the Pearl River Delta, China”, Research Policy, Vol. 42 No. 3, pp. 635–646.

González-Pernía, J.L., Parrilli, M.D. and Peña-Legazkue, I. (2015), “STI–DUI learning modes, firm–university collaboration and innovation”, The Journal of Technology Transfer, Vol. 40 No. 3, pp. 475–492.

Gruner, K. and Homburg, C. (1998), Customer interaction as a key to new product success, Reihe: Wissenschaftliche Arbeitspapiere / Institut für Marktorientierte Unternehmensführung, Universität Mannheim, Vol. 16, [Nachdr. der Ausg.] Koblenz, 1998, Inst. für Marktorientierte Unternehmensführung, Mannheim.

Hall, B.H. and Jaffe, A.B. (2018), “Measuring Science, Technology, and Innovation: A Review”, Annals of Science and Technology Policy, Vol. 2 No. 1, pp. 1–74.

Haus-Reve, S., Fitjar, R.D. and Rodríguez-Pose, A. (2019), “Does combining different types of collaboration always benefit firms? Collaboration, complementarity and product innovation in Norway”, Research Policy, Vol. 48 No. 6, pp. 1476–1486.

Herstad, S. and Brekke, T. (2012), “Globalization, Modes of Innovation and Regional Knowledge Diffusion Infrastructures”, European Planning Studies, Vol. 20 No. 10, pp. 1603–1625.

Hippel, E. von and Tyre, M.J. (1995), “How learning by doing is done: problem identification in novel process equipment”, Research Policy, Vol. 24 No. 1, pp. 1–12.

Holtskog, H. (2017), “Forms of Innovation—Insights from Product Development”, Journal of the Knowledge Economy, Vol. 8 No. 1, pp. 63–76.

Howells, J. (1996), “Tacit knowledge”, Technology Analysis & Strategic Management, Vol. 8 No. 2, pp. 91–106.

Isaksen, A. and Karlsen, J. (2010), “Different Modes of Innovation and the Challenge of Connecting Universities and Industry: Case Studies of Two Regional Industries in Norway”, European Planning Studies, Vol. 18 No. 12, pp. 1993–2008.

Isaksen, A. and Karlsen, J. (2012a), “Combined and Complex Mode of Innovation in Regional Cluster Development: Analysis of the Light-Weight Material Cluster in Raufoss, Norway”, in Asheim, B.T. and Parrilli, M.D. (Eds.), Interactive learning for innovation: A key driver within clusters and innovation, Vol. 20, Palgrave Macmillan, [Place of publication not identified], pp. 115–136.

Isaksen, A. and Karlsen, J. (2012b), “What Is Regional in Regional Clusters? The Case of the Globally Oriented Oil and Gas Cluster in Agder, Norway”, Industry & Innovation, Vol. 19 No. 3, pp. 249–263.

Isaksen, A. and Karlsen, J. (2013), “Can small regions construct regional advantages? The case of four Norwegian regions”, European Urban and Regional Studies, Vol. 20 No. 2, pp. 243–257.

Isaksen, A., Martin, R. and Trippl, M. (Eds.) (2018), New avenues for regional innovation systems: Theoretical advances, empirical cases and policy lessons, 1st edition 2018, Springer, Cham.
Isaksen, A. and Trippl, M. (2017), "Innovation in space. The mosaic of regional innovation patterns", Oxford Review of Economic Policy, Vol. 33 No. 1, pp. 122–140.
Jensen, M.B., Johnson, B., Lorenz, E. and Lundvall, B.Å. (2007), "Forms of knowledge and modes of innovation", Research Policy, Vol. 36 No. 5, pp. 680–693.
Johnson, B. (2010), "Institutional Learning", in Lundvall, B.-Å. (Ed.), National systems of innovation: Toward a theory of innovation and interactive learning, Anthem Press, London, pp. 23–46.
Kepper, G. (1996), "Qualitative Marktforschung", Methoden, Einsatzmöglichkeiten und Beurteilungskriterien, Vol. 2.
Lundvall, B.-Å. (1985), Product innovation and user-producer interaction, Industrial development research series, 31 Research report, Univ. Press, Aalborg.
Martin, R., Moodysson, J. and Zukauskaite, E. (2011), "Regional Innovation Policy Beyond 'Best Practice'. Lessons from Sweden", Journal of the Knowledge Economy, Vol. 2 No. 4, pp. 550–568.
Marzucchi, A. and Montresor, S. (2017), "Forms of knowledge and eco-innovation modes: Evidence from Spanish manufacturing firms", Ecological Economics, Vol. 131, pp. 208–221.
Massis, A. de, Audretsch, D., Uhlaner, L. and Kammerlander, N. (2018), "Innovation with Limited Resources: Management Lessons from the German Mittelstand", Journal of Product Innovation Management, Vol. 35 No. 1, pp. 125–146.
Mayring, P. (2002), Einführung in die qualitative Sozialforschung, Beltz Verlag.
Mayring, P. (2010), Qualitative Inhaltsanalyse: Grundlagen und Techniken [Qualitative Content Analysis. Basics and technics], Neuausgabe, Beltz Verlagsgruppe, s.l.
Mohr, L.A. and Bitner, M.J. (1991), "Mutual Understanding Between Customers and Employees in Service Encounters", ACR North American Advances, NA-18.
Nunes, S. and Lopes, R. (2015), "Firm Performance, Innovation Modes and Territorial Embeddedness", European Planning Studies, Vol. 23 No. 9, pp. 1796–1826.
Pahnke, A. and Welter, F. (2019), "The German Mittelstand: antithesis to Silicon Valley entrepreneurship?", Small Business Economics, Vol. 52 No. 2, pp. 345–358.
Parrilli, M.D. and Elola, A. (2012), "The strength of science and technology drivers for SME innovation", Small Business Economics, Vol. 39 No. 4, pp. 897–907.
Parrilli, M.D., Fitjar, R.D. and Rodríguez-Pose, A. (2016), Business Innovation Modes: A Review From a Country Perspective, Routledge, available at: https://content.taylorfrancis.com/books/download?dac=C2014-0-58333-1&isbn=9781315671475&doi=10.4324/9781315671475-20&format=pdf.
Parrilli, M.D. and Heras, H.A. (2016), "STI and DUI innovation modes. Scientific-technological and context-specific nuances", Research Policy, Vol. 45 No. 4, pp. 747–756.
Rammer, C., Czarnitzki, D. and Spielkamp, A. (2009), "Innovation success of non-R&D-performers: substituting technology by management in SMEs", Small Business Economics, Vol. 33 No. 1, pp. 35–58.
Robertson, P.L. and Patel, P.R. (2007), "New wine in old bottles: Technological diffusion in developed economies", Research Policy, Vol. 36 No. 5, pp. 708–721.
Romer, P.M. (1990), "Endogenous technological change", The Quarterly Journal of Economics, Vol. 98 No. 5, Part 2, S71-S102.
Rosenberg, N. (1982), Inside the Black Box: Technology and Economics.
Schreier, M. (2007), "Qualitative Stichprobenkonzepte", in Naderer, G. and Balzer, E. (Eds.), Qualitative Marktforschung in Theorie und Praxis, Vol. 15, Gabler, Wiesbaden, pp. 231–245.
Solow, R.M. (1957), "Technical Change and the Aggregate Production Function", The Review of Economics and Statistics, Vol. 39 No. 3, p. 312.
Starr, M.A. (2014), "Qualitative and mixed-methods research in economics: surprising growth, promising future", Journal of Economic Surveys, Vol. 28 No. 2, pp. 238–264.
Thomä, J. (2017), "DUI mode learning and barriers to innovation—A case from Germany", Research Policy, Vol. 46 No. 7, pp. 1327–1339.
Thomä, J. and Zimmermann, V. (2019), "Interactive learning — The key to innovation in non-R&D-intensive SMEs? A cluster analysis approach", Journal of Small Business Management, pp. 1–30.
Tödtling, F., Lehner, P. and Trippl, M. (2007), "Innovation in knowledge intensive industries. The nature and geography of knowledge links", European Planning Studies, Vol. 14 No. 8, pp. 1035–1058.
Trippl, M. (2011), "Regional Innovation Systems and Knowledge-Sourcing Activities in Traditional Industries—Evidence from the Vienna Food Sector", Environment and Planning A, Vol. 43 No. 7, pp. 1599–1616.