Research Policy 50 (2021) 104214

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

A New Measurement Conception for the 'Doing-Using-Interacting' Mode of Innovation

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ARTICLE INFO

Jel:
C81
O3
O31

Keywords:
DUI
STI
innovation indicator
learning process
modes of innovation
measurement

ABSTRACT

The 'doing-using-interacting' (DUI) mode of innovation describes informal innovative activities and it can be juxtaposed with the 'science-technology-innovation' (STI) mode based on deliberate research and development. While both modes contribute substantially but differently to technological progress, our empirical understanding of DUI mode innovative activity suffers from the lack of a comprehensive measurement approach. While empirical measurement of the STI mode is well established, empirical indicators for DUI activities are scarce and no consensus has emerged concerning its constituting learning processes. We propose a new measurement conception for innovative activity and based on 81 in-depth interviews with German firms and regional innovation consultants. We derive fifteen categories of DUI mode learning processes and a comprehensive set of 47 indicators comprising both established and new DUI indicators for empirical measurement. This new measurement conception and the respective indicators provide a holistic perspective and their application can be used to increase our understanding of the importance of DUI mode innovative activity, as well as guiding policy-makers.

1. Introduction

Innovative activities are the central determinant of national, regional and firm-level economic development and growth. However, assessing and measuring the underlying processes of learning and knowledge accumulation has been an ongoing challenge for decades (Abramovitz, 1956; Solow, 1957; Dosi, 1988; Dosi *et al.*, 1988; Romer, 1990). The established measurement of innovative activities captures formal R&D via e.g. R&D expenditures, publications and patents or the share of highly-qualified employees (e.g. Smith, 2005; Mairesse and Mohnen, 2010; Hall and Jaffe, 2018; OECD, 2015; OECD, 2018), although this approach falls short in explaining innovative activity for a substantial share of firms. For example, Peters *et al.* (2017) show that about 22% of innovative firms in Germany do not rely on traditional R&D expenditures for their innovation activity. Therefore, a substantial share of innovative activity is not captured by established formal R&D indicators, encompassing informal learning processes within the firm or via external interactions with suppliers or customers (Jensen *et al.*, 2007; Apanasovich, 2016; Apanasovich *et al.*, 2017). The differentiation of innovative activities that are conducted deliberately via formal R&D and those that happen alongside other activities results in two ideal-typical modes of innovation, namely the 'science-technology-innovation' (STI) mode and the 'doing-using-interacting' (DUI) mode of innovation (Jensen *et al.*, 2007).

STI mode innovation typically relies on codified, 'know-what' and 'know-why' knowledge, it is conducted by R&D departments, in cooperation with research institutes or other firms, and based on its codifiability it tends to have a rather global reach (Jensen *et al.*, 2007; Nunes and Lopes, 2015). Learning in STI primarily means searching for new knowledge such as scientific principles and recombining knowledge to achieve substantial innovative progress (Brooks, 1994). In this mode, formal R&D activity is the main driver of innovation, resulting in new products or processes, and it is effectively measured empirically by established indicators such as patents, R&D personnel and expenditures (e.g. Smith, 2005; Mairesse and Mohnen, 2010; Hall and Jaffe, 2018; OECD 2015, 2018). Measuring such activities served as the foundation

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https://doi.org/10.1016/j.respol.2021.104214
Received 28 February 2020; Received in revised form 26 January 2021; Accepted 2 February 2021
Available online 23 February 2021

for researchers to understand innovation in general, and it is used to advice policy-makers on how and where to implement governmental support for innovation. However, these measures fall short in capturing the innovation process in firms that do not rely on such activities (e.g. Arrow, 1962; Rosenberg, 1982; Lundvall, 1985; Jensen *et al.*, 2007).

Due to its informal nature, DUI mode innovation cannot be measured by indicators focused on formal R&D activities. Indeed, DUI is defined as a by-product of other activities and it often results in tacit knowledge with a focus on 'know-how' and 'know-who', which tends to have a rather local reach in terms of its connections to customers, suppliers and competitors (Johnson *et al.*, 2002; Jensen *et al.*, 2007). DUI constitutes processes of learning through 'doing', i.e. learning from working experience, increasing the skill in production and exchanging knowledge within the firm (Arrow, 1962; Thompson, 2010). Furthermore, it involves 'using', meaning e.g. feedback from users and their involvement in improving or co-creating products and services (Rosenberg, 1982). Finally, it comprises 'interacting', i.e. learning through interaction with other firms or external actors, such as suppliers or public institutions (Lundvall, 1985; Jensen *et al.*, 2007). These three broader learning processes result in innovations that are usually of incremental nature such as cost reductions or quality improvements, but they can also generate new products or services, which are often highly customer-specific (Apanasovich *et al.*, 2016; Jensen *et al.*, 2007; Nunes and Lopes, 2015; Parrilli and Heras, 2016).

While the measurement of innovative activity is well established for STI activities, it is conceptually and empirically underdeveloped for DUI mode activities. In general, we lack a comprehensive measurement approach for the DUI mode activities and existing research suffers from a mismatch between the theoretical concept of DUI activities and its empirical measurement. Foremost, the lack of targeted indicators for learning-by-doing and learning-by-using is particularly critical. The majority of quantitative studies measure DUI innovativeness based on a firm's external interactions and neglect substantial parts of the DUI activities (Apanasovich, 2016). For example, several studies only measure learning-by-interacting and omit measuring learning-by-doing and learning-by-using (e.g. Chen *et al.*, 2011; Fitjar and Rodríguez-Pose, 2013; González-Pernía *et al.*, 2015, Parrilli and Heras, 2016). Some studies try to compensate this by relying on existing indicators which are only loosely related to these types of learning. For example, the expenditures related to the preparation of production and marketing expenditures are used as proxies for these types of DUI activities (e.g. Apanasovich et al., 2016; Marzucchi and Montresor, 2017). The lack of a theoretical measurement framework and comprehensive set of indicators for the DUI mode hampers our understanding of innovative activity in general and falls short in providing information for relevant policy implications on how to support DUI mode innovative activity.

To address this measurement problem, we provide a novel and comprehensive measurement conception to access DUI mode innovative activities. For this purpose, we first develop a framework to derive starting points for measuring innovative activities in the different innovation modes. We suggest measuring innovative activity via knowledge flows and facilitators. Second, we use this framework to guide semi-structured interviews with firms and regional innovation consultants to understand learning and knowledge production processes in firms. Third, we use the interviews and combine them with the existing DUI literature and propose indicators and measurement approaches for the DUI mode. We apply an inductive approach to generate the items as suggested by Hinkin (1998). This set of indicators enables capturing the different flows of knowledge related to knowledge accumulation as well as the relevant facilitators in the firm to capture, augment and redirect the knowledge flows into economic application. Based on the suggested indicators, researchers and policy-makers are enabled to conduct surveys to assess DUI mode innovative activities, complement existing STI-based surveys and develop evidence-based support for DUI mode innovation activity.

For our qualitative assessment of the DUI mode activities and the construction of empirical indicators, we approached small and medium-sized enterprises (SMEs) with one to 250 employees from the 'German Mittelstand'. This group of firms from the German economy has been emphasized as exemplary for its strong innovative performance with limited resources, mostly without formal R&D (Pahnke and Welter, 2019; Massis *et al.*, 2018). They serve as an ideal case to observe the different DUI mode innovation activities since they are very heterogeneous and rely on different sources of knowledge. We conducted 49 in-depth semi-structured interviews with SME representatives to understand which firm-related processes are integral to the DUI mode. These firms are located in three German regions, namely Göttingen, Hanover and East-Thuringia. We complement this with 32 semi-structured interviews with innovation consultants from these regions to understand overarching patterns and regional particularities that influence innovative activity.

Based on our assessment, we propose 47 indicators to measure DUI mode innovative activity. We group them in fifteen categories and distinguish them into measures for knowledge flows and facilitators. We furthermore suggest how these DUI measures can relate to STI activities and how their interaction can be assessed. The different measures are provided in ready-to-use form in full or selectively in the Supplementary Material. Based on these indicators, a large-scale measurement of innovative activity in the DUI mode and how it complements existing STI measures can provide additional insights into economic theory and serve as a foundation for policy support, especially for SMEs, which predominantly use DUI mode innovation activities and do not benefit from STI-based policy instruments.

In the following Section 2, we propose a measurement conception for the two modes of innovation and discuss how especially DUI mode innovative activity can be measured. Section 3 describes our qualitative methodological approach to determine the central DUI processes. Section 4 presents our findings and the set of indicators for measuring DUI processes. Finally, Section 5 concludes.

2. Conceptualizing DUI mode innovative activity and its measurement

2.1. Modes of innovation

Innovation and technological change are results of knowledge exchange and recombination (Schumpeter, 1911; Dosi and Nelson, 2010). The underlying innovation process comprises knowledge accumulation, which takes place via internal processes, especially interaction in the firm, but also via interaction with external actors (Kline and Rosenberg, 1986). Such processes can be deliberately conducted or happen as a by-product of other activities. Based on these different processes of knowledge generation and exchange, a stream of literature separates innovative activity in a mode that follows the logic of science-technology-innovation, called STI, and a mode that focuses on learning via doing, using and interacting, called DUI (Jensen *et al.*, 2007; Apanasovich, 2016). Inherent to both modes is the exchange and flow of knowledge. However, the kind of knowledge generated and shared differs between the two modes. While in the STI mode primarily scientific and codifiable knowledge is generated and exchanged, the DUI mode knowledge generation and exchange is characterized by its tacit nature (Cowan *et al.*, 2000; Jensen *et al.*, 2007).

STI mode activity encompasses the deliberate search for new solutions such as new products or new processes. Controlled experimenting and reasoning are used to generate new knowledge, opening up new technological possibilities, and providing new tools and instruments (Brooks, 1994). It involves intentional learning via education, training, research and development, or market research (Lundvall and Johnson, 1994). These processes can take place within the firm, but also in interaction with actors outside of the firm, especially research organizations (Malerba, 1992). These processes generate new knowledge, which serves as an input for innovative output. A prerequisite for this

kind of learning or knowledge acquisition is sufficient absorptive capacity (Cohen and Levinthal, 1990).

By contrast, innovations by DUI mode activities do not emerge from such deliberate, scientific processes, but rather they take place while undertaking regular activities in the firm, exchanging with users or via other forms of interactions with other firms or actors (Jensen *et al.*, 2007). *Learning-by-doing* describes a process of repeated exercise of an activity – doing something – which increases the efficiency of that task (Arrow, 1962; Thompson, 2010). Hence, the individual who carries out a task is the one who reaps such learning effects, reflecting the simplest form of learning-by-doing (Arrow, 1962). Moreover, failing and learning from mistakes are also important in this process (Frese and Keith, 2015). Furthermore, we can apply this idea to the level of teams and other organizational forms, such as departments or firms. Here, learning-by-doing can be thought of as joint learning activities among different actors within a firm (Parrilli and Elola, 2012; Thomä and Zimmermann, 2020; Sandvik *et al.*, 2020). They exchange knowledge and experiences, eventually leading to new knowledge and improvements of products and processes (Thompson, 2010). Such joint or collective learning-by-doing comprises several activities, e.g. the common identification of problems caused by changes in the environment are potential starting points of learning-by-doing (von Hippel and Tyre, 1995).

Learning-by-using describes a process in which customers or users of a product or service report back their experience of using the product. Rosenberg (1982) provides several examples where users reported their experiences and influenced the future design and properties of products. This feedback from users outside of a firm contributes to knowledge accumulation and innovation opportunities for the firm. In its simplest form, users report problems back to the firm, and the firm improves the product (Mukoyama, 2006). However, users can also articulate a specific demand for a product variation or a new product. Thereby, the communication between users and producers – especially over a longer period of time – is important to understand the users' needs to improve and re-design the product or service offered by the producer (Habermeier, 1990; van der Heijden *et al.*, 2013). Indeed, it can even lead to co-creation with users (von Hippel, 1988; Bogers *et al.*, 2010).

Learning-by-interacting describes the process by which the firm interacts with other firms or actors outside of the firm provide learning and innovation opportunities from spillovers (Lundvall and Johnson, 1994; Dahl and Pedersen, 2004). The interaction of firms with heterogeneous sets of knowledge – usually firms that are not competing in the same market – is a major source of learning and innovation (Fitjar and Rodríguez-Pose, 2013). Other actors such as suppliers, distributors, and competitors provide additional learning opportunities (Haus-Reve *et al.*, 2019). Especially interaction in an informal way, for example, via meetings with former colleagues or at trade fairs, can serve as a source of new knowledge (Dahl and Pedersen, 2004; Thomä and Zimmermann, 2020). The knowledge that is generated or received contributes to knowledge accumulation and serves as an input in the innovation process.

Inherent to the three different DUI learning processes is that they relate to knowledge that answers questions of 'know-how' and 'know-who'. They focus on problem-oriented learning and the knowledge that is generated and learned is of tacit nature. This can be juxtaposed to the STI learning processes which rely on codified knowledge related to questions of 'know-what' and 'know-why'. Nevertheless, these two modes of innovation frequently co-exist to different degrees in firms and pure DUI or pure STI firms are rare cases (Jensen *et al.*, 2007; Thomä, 2017; Alhusen and Bennat, 2020). Usually, firms that combine both modes of innovation show higher innovative performance (Parrilli and Heras, 2016; Thomä, 2017). The combination and utilization of both modes of knowledge generation can lead to superior outcomes, which can also be attributed to the kind of knowledge generated respectively. The scientific, explicit knowledge generated from STI processes can be better utilized if it is complemented by the implicit and often tacit knowledge generated via DUI mode activities.

2.2. Measuring modes of innovation

While the theoretical separation of the two modes of innovation is well established, the empirical measurement to elaborate their influence on innovative activity and performance is an open issue (Apanasovich, 2016). The conceptual measurement problem is thereby straight forward as the two modes of innovation are intertwined:$Innovative\ Output = f(STI) + g(DUI) + h[(STI)^*(DUI)]$. In this model, *(STI)* and *(DUI)* depict the knowledge inputs generated by the two modes of innovation. They individually have a respective influence f or g on the innovative output, while their joint presence $[(STI)^*(DUI)]$ also holds importance and contribute via h.

Empirically, multiple measures for (*STI*), such as R&D expenditures, R&D personnel, patents or STI-based innovation surveys are well established (e.g. Hall *et al.*, 2010; Hong *et al.*, 2012; Hall and Jaffe, 2018; OECD, 2015, 2018). However, no comprehensive set of measures for (*DUI*) has been developed to date. Several eclectic approaches exist to capture DUI mode innovative activity and learning processes, but conceptually they are usually not well grounded (see also the discussion in Apanasovich, 2016). Such absence of a comprehensive and reliable set of measures for the DUI mode of innovation is particular problematic, since they complement and enhance (*STI*) (e.g. Parrilli and Heras, 2016; Thomä, 2017). This biases the empirical assessment of innovation activities downwards and tends to understate them, especially for firms that focus more on DUI activities (Alhusen and Bennat, 2020). To overcome this problem and to derive proper measures for the DUI mode of innovation, we propose a measurement conception in line with the feedback model of the innovation process where the modes of innovation comprise the firm's internal and external interactions (Kline and Rosenberg, 1986). In this conception, the measures for DUI activities as well as equivalently STI activities can be grouped in two kinds of measures.

First, we propose measuring **flows of knowledge** that emerge within the firm via doing, and flows of knowledge that come from outside of the firm via using and interacting. These flows contain new knowledge for the receiving firm, which serves as an input for innovation activities. The flows of knowledge can be measured with respect to their intensity or quality. The respective magnitudes can be used to understand the type, quantity and quality of the firm's innovative output. Although measuring knowledge flows is difficult (Krugman, 1991), several approaches exist to capture them (Breschi and Lissoni, 2001a; Breschi and Lissoni, 2001b). While there is ample research on how to measure knowledge flows from STI activity (e.g. Griliches, 1992; Jaffe *et al.*, 1993; Kaiser, 2002), measuring knowledge flows for DUI activities is essentially absent thus far and challenging due to their tacit nature.

Second, we propose measuring **facilitators**, which are essential actors, organizational practices or technical means in the firm that capture, augment and promote flows of new knowledge and help to translate them into economic application. They are essential to distribute new knowledge to those actors in the firm using it to improve or create new products, processes or services (Rothwell, 1977). Furthermore, facilitators allow for feedbacks to the sources of knowledge flows and establish exchange in both directions. Such facilitators include knowledge management tools, practices of team rotation or customer contact points (Darroch, 2003). Without proper facilitators in place, flows of knowledge do not reach the firm or are not directed towards actors who can utilize them. For example, if no mechanism to distribute feedback from customers to the appropriate actors exists, the inflow of knowledge cannot be utilized and users' knowledge cannot be integrated in the innovation process. Facilitators can be measured in a qualitative and quantitative way.

Both types of measures may help to assess – albeit differently – how knowledge is generated and flows into the firm, as well as how it is applied within the firm. Figure 1 depicts the different modes of

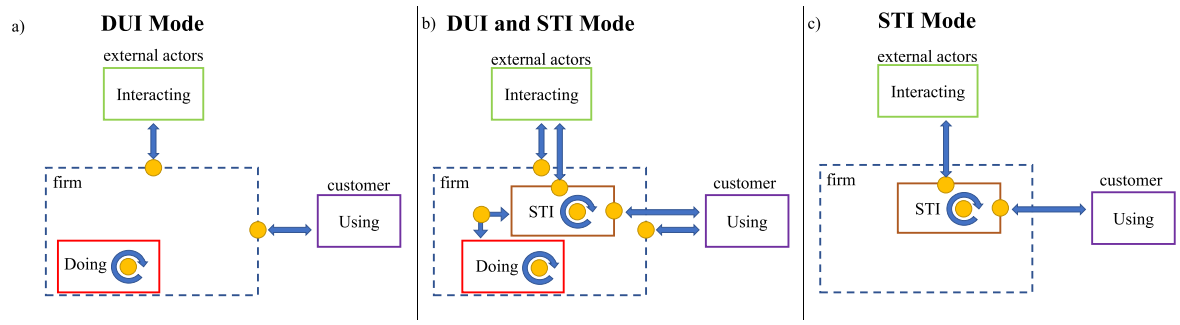

Figure 1. Measurement conception for the different modes of innovation.
Note: The dashed rectangle represents the firm. Within the firm, (learning by) doing as well as STI processes take place, represented by circular arrows. Outside of the firm are customers as well as other external actors. Arrows represent bi-directional knowledge flows representing (learning by) using and (learning by) interacting. Dots represent facilitators.

innovation and the points of measurement. In panel a) of the Figure, the DUI mode is depicted, and in panel c) the STI mode. Panel b) shows the combination of both modes and their interaction (Alhusen and Bennat, 2020). The firm (rectangle with permeable boundaries) is in the center of the concept. Outside of the firm are external actors with which the firm interacts, as well as a special subgroup, namely customers. Arrows represent knowledge flows within the firms or from outside into the firm. Thereby, knowledge exchange can be bi-directional. Facilitators are represented by circles and they redirect, augment or capture the knowledge flows. Each arrow and circle represent the points of measurement.

The DUI mode of innovation is presented in panel a) of Figure 1. *Learning-by-doing* takes place within the firm. Knowledge is generated and exchanged in the process of executing tasks and it is used to improve the task itself or its outcome at hand (Arrow, 1962; Thompson, 2010). These activities generate knowledge as a by-product and its application creates a flow of new knowledge, which needs to be measured. Since such activities are distributed across actors, their firm-internal interaction is a key flow of knowledge for innovative activity as it allows for inter-individual, collective learning and expands the space for knowledge recombination. Facilitators within the firm are required to distribute the knowledge generated to other actors in the firm to implement it at the appropriate point; for example, via knowledge management systems or internal trainings (e.g. Thomä and Zimmermann, 2020). Especially for the interaction within the firm, facilitators need to be in place to augment the flow of knowledge, encourage the interaction of different actors within the firm or allow for changes in the production process; for example, via quality circles or staff exchange programs (Jensen *et al.*, 2007; Parrilli and Elola, 2012; Nunes and Lopes, 2015). Empirically assessing the internal flows of knowledge as well as measuring the presence and the extent of utilization of such facilitators is key to assessing the use of knowledge for learning-by-doing in the firm.

Knowledge from *learning-by-using* is generated external to the firm through the use of its products and services by customers (Rosenberg, 1982). The knowledge generated by the customers flows from them into the firm or is co-created in close interaction. Such knowledge reaches the firm in several ways, via customer feedback or via integrating customers into the development of prototypes or for testing purposes (Cantner et al., 2021). For the knowledge to be received by the firm, proper facilitators need to be in place to capture the knowledge from the users and make it usable for the firm, directly or via co-creation. For the innovative potential of external knowledge flows to materialize, facilitators are needed to open up the firm's boundaries and direct the knowledge to the relevant actors within the firm that put it to application. Measuring the knowledge flows from customers and how they are facilitated in the firm is essential to assessing how learning-by-using takes place and influences innovative activity.

Learning-by-interacting takes place with other actors outside of the firm. Knowledge flows into the firm from actors such as competitors, suppliers or other third parties via different channels. External actors might be quite different in type, and they provide different knowledge and transfer it via different channels. For example, suppliers can provide additional information about a product, which could improve its usage or reduce costs. The firm can also co-create new knowledge with suppliers or competitors (Chen *et al.*, 2011; Fitjar and Rodríguez-Pose, 2013; González-Pernía *et al.*, 2015; Parrilli and Heras, 2016). Facilitators are necessary to capture and distribute the knowledge flows from outside into the firm. For example, if suppliers provide additional information about a product, the knowledge needs to be distributed within the firm to the relevant actors. The knowledge flows from learning-by-interacting are frequently measured in network connections, although the magnitude of the flows as well as the respective facilitators are not yet well measured.

Panel c) in Figure 1 depicts the STI mode. STI activities are usually not a separate component of knowledge creation and innovative activity in the firm, but rather closely integrated into it. Hereby, knowledge is generated and accumulated via deliberate research activities, and also co-created with customers (von Hippel, 1976) and other firms in joint research projects or in collaboration with research organizations (Brooks, 1994). The flows of knowledge from outside of the firm can emerge from actors similar to those that are important for DUI activities, but they are created and captured deliberately e.g. via joint research projects. The knowledge flows and their content can be measured directly via publications or patents generated in such collaborations (e.g. Breschi and Catalini, 2010). For these activities to translate into innovative outcomes, they also need facilitators to transmit the generated knowledge into application and manage the interaction with external actors (Grant, 1996). Here, facilitators can be research labs or intellectual property rights managers. Overall, the STI mode of innovation is well understood and the related measures are established and formalized (OECD, 2015, 2018).

Panel b) in Figure 1 shows that STI and DUI are usually not distinct modes that a firm decides between, but rather they co-exist in a firm and interact (Jensen *et al.*, 2007; Thomä, 2017; Alhusen and Bennat, 2020). Often they are complementary[1] and knowledge flows take place between the two modes. With respect to firm internal knowledge generating processes, for example, an exchange of problems and solutions takes place between the production site – as a locus of learning-by-doing – and the research department – as a locus of deliberate R&D. Proper facilitators for the exchange need to be in place to manage such exchanges, since communication within different departments can be hampered (Parrilli and Elola, 2012; Fu *et al.*, 2013). A typical example is

[1] However, in some instances, the combination of DUI and STI mode activities can be substitutional, as Haus-Reve *et al.* (2019) document for specific learning-by-interacting and STI activities.

that facilitators between the production side and the R&D laboratory need to exist to facilitate knowledge flows and exchange, since the persons may not use the same terminology or may not know whom to approach. Understanding and measuring the resulting internal knowledge flows and necessary facilitators has been partly addressed by the innovation management literature, which suggests a larger set of potential indicators to capture such relationships (e.g. Darroch, 2003; Yi, 2009). However, most of these measurement approaches focus on STI activity and do not take into account the DUI dimension. Similar interdependencies hold also for respective processes that include customers and other external actors as discussed partly in the open innovation literature (Chesbrough, 2003; Bogers *et al.*, 2010).

This stylized conception of how DUI and STI mode innovative activities take place, how knowledge flows into and within the firm, and how facilitators play a role herein serves as a starting point to develop empirical indicators. Contrary to STI activities – where many indicators exist concerning how to capture the knowledge flows and the facilitators that need to be in place – empirical indicators for DUI activities are scarce and scattered across different streams of literature (Apanasovich, 2016). The combination of measures for knowledge flows and facilitators allows for a broadened view where the capabilities to access new knowledge and learning are combined with the innovative potential that such new knowledge embraces. In the following, we report on qualitative interviews that we conducted to elicit which flows of knowledge occur – especially for DUI mode activities – and which facilitators are used to make use of such knowledge flows within the firm. Based on these interviews in conjunction with existing empirical evidence, we propose a set of indicators to measure DUI mode innovation activity.

3. Method and data

3.1. Methodological approach

We used an exploratory qualitative research design to understand the DUI-relevant processes of informal learning activities and derive respective measurement items for a quantitative assessment of DUI mode innovative activity (Moskaliuk and Cress, 2016). Based on the measurement conception developed in Section 2 and an extensive review of the empirical DUI literature, we developed two semi-structured interview guidelines that prompt the interviewees to explain learning processes at the firm and regional level. We interviewed firm representatives and asked them about their firm-specific innovative activities and learning processes, as well as regional innovation consultants to gain insights at an aggregated level and understand regional particularities in innovative activities.

The interview guidelines for firm representatives contain questions concerning some general individual and firm characteristics, as well as a series of questions concerning innovative activity and learning processes. Most of these questions address processes that can be attributed to DUI mode activities, but also questions concerning STI activities were asked to differentiate the different learning processes. The interview guidelines for regional innovation consultants also contain basic individual characteristics but mainly focus on innovative activity and regional interaction relationships. Both guidelines were tested 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 the Appendix.

In the interviews, researchers encouraged respondents to share their own views and experiences in innovative activity, as well as how they conduct such activity. Since 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 interviewees' 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. This open qualitative approach enables us to gain a deeper understanding of the innovative activities and the role that knowledge flows and facilitators play in DUI mode innovative activity.

3.2. Interview sample and sampling procedure

The theoretical concept of innovation modes is vague in defining core processes manifesting each innovation mode. To gain a better understanding, we sampled cases that are helpful to construct a corpus of empirical examples for studying the phenomenon of interest, capturing the variation and variety in the phenomenon of innovation modes as much as possible (Flick, 2018). Consequently, the purpose of sampling is not representativity, but instead the exhaustion of relevant cases and depiction of their heterogeneity. When theoretical concepts are under-developed, a more "loose design" (Miles and Huberman, 1994) is appropriate, offering the openness and flexibility as needed (Flick, 2018). Therefore, reaching the goal of covering the different DUI activities, we used a purposive sampling strategy seeking cases from three different German regions that assert themselves as innovative and capture the heterogeneity in innovative activity.

For our sampling, we focus on the three German planning regions[2] of Göttingen, Hanover and East-Thuringia. The regions were chosen for their fairly similar socio-economic structures, according to the principles of contrasting comparison (Ward 2010); Wolff and Haase, 2020). All regions include metropolitan areas, which implies organizationally thick regional innovation systems, albeit with different industry specializations (Isaksen and Trippl, 2017, p. 125; Isaksen *et al.*, 2018). All three regions qualify as being characterized by the 'German Mittelstand', meaning firms that are rather small and locally embedded, without integration into larger corporations or substantial R&D involvement, while being internationally competitive and innovative. Universities and research centers are located in all regions. Moreover, the support structures of innovation consultants from public or semi-public institutions are fairly similar across the regions. Table 1 presents the number of interviewees by region and interviewee type.

We identified the relevant cases, especially firms via an extensive web search, assessed participants in regional innovation contests, used snowball sampling[3] and relied on suggestions by regional innovation consultancies. We simultaneously conducted the interviews and first analysis of them and stopped interviewing additional firms when we reached a level of saturation and no new information was generated from further interviews. Furthermore, we mainly selected firms that supposedly innovate in the DUI mode, but our sample also contains firms that engage in STI-related activities to different degrees, such as having an R&D department, conducting occasional R&D activities or cooperating with science-based partners. We limited the sample to SMEs with up to 250 employees. Interviewing SMEs holds particular relevance in our case, because in such firms access to the relevant interview partner is possible and the interviewees can provide holistic insights into the firm's

Table 1
Number of interviews by region and type.

	Göttingen	Hanover	East-Thuringia	Total
Firm representatives (F)	18	15	16	49
Regional innovation consultants (C)	11	12	9	32

[2] There are 96 German planning regions – 'Raumordnungsregionen' – which represent functionally-integrated spatial units comparable to labor market areas in the United States.

[3] Snowball sampling is appropriate in our case, since interference between the cases can be negated given that the firms do not influence each other's innovation activity in our interview sample (Schreier, 2007).

internal and external learning processes. Unlike quantitative research, this procedure provides us with a small group of highly relevant observations rather than a random, extensive sample, which serves our research aim to understand the heterogeneity in the processes (Schreier, 2007, p. 233).

Following this sampling procedure, we interviewed 49 firm representatives (mostly CEOs) who possess detailed knowledge about their firm's innovation processes. Since we are looking for patterns of learning processes in general, we conducted interviews with firms from different industries to gain a broader picture of the variety of processes. Table O1 in the Supplementary Material provides an overview of the industry NACE Rev. 2 classifications for the firms in our sample. The average firm size is 49 employees, with a median of 25. Furthermore, we interviewed 32 regional innovation consultants, who 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 offer an internal, quite idiosyncratic view on their learning processes, including the consultants' perspective provides a more holistic picture of the respective learning processes. To distinguish between the two groups 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. The interviews lasted 62 minutes on average, depending on the openness of our interviewees and their level of insight into learning processes. More detailed information on firm and consultant specifics as well as the interview lengths is provided in the Supplementary Material Table O2 and O3.

3.3. Qualitative analytical procedure

While ensuring anonymity, the interviews were recorded on tape and in one case in written form, where the interviewee did not agree to recording. 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.

The development of a category system is at the core of our analysis. The category system was deductively developed from the measurement conception as well as the two interview guidelines and subsequently it was inductively expanded by categories that the material contains (Mayring, 2002, p. 114 - 121). We incrementally reduced the content of the interviews to those statements that characterize the learning processes. To ensure the reliability of the qualitative analysis, we conducted 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. intercoder reliability). The results were saved in code memos and the categories were extensively discussed and assessed in the researcher team (Mayring, 2002, p. 119). Afterwards, the categories were used to summarize and contrast the aspects that the interviewees mentioned. Accordingly, we aim to understand DUI learning at the firm level before identifying measurement options. Based on the interviews, we aggregate the different responses into core processes that are prevalent in the firms in our sample. These core processes are categorized in specific areas of measurement and complemented with the existing literature. We then derive specific items for an empirical assessment of the respective DUI innovative activity in terms of knowledge flows and facilitators.

4. A new conception of DUI measurement indicators

4.1. Categorization of DUI mode learning processes

In most cases, our interviewees were very responsive and eager to share information about learning and innovation processes in their firms, as well as their holistic view on these processes in case of the regional innovation consultants. In all firm interviews, the relevance of DUI mode innovative activity was highlighted in different degrees, as well as the importance of experience-based know-how and the exchange of knowledge. This is usually confirmed by the regional innovation consultants. One consultant summarized the importance of experience-based knowledge in his region as follows: "*… the opportunity to see best practice and learn from it also encourages own developments and own implementations [in firms]. And you can also discuss the examples you have seen somewhere in your own team, with your own organization, and put them up for discussion. This can lead to ideas and creative solutions"* (C16). Interestingly, we found also cases where consultants seem to neglect the importance of experience-based knowledge as relevant for innovation: *"Experience knowledge only plays a role if the experience is based on previous innovations. Otherwise, pure professional experience, professional competences, many years of professional experience do not play a role for innovation, my experience"* (C14). However, in the further course of these interviews it often turned out that these statements were based on a limited understanding of innovation, which did not include process innovations, efficiency gains, or organizational changes which are core DUI-related innovative outcomes.

The aggregation of the different examples and insights into the three larger DUI process strands of doing, using and interacting revealed substantial heterogeneity across the firms, industries and regions. Some firms heavily relied on learning-by-doing but not on other means of learning, while others tried to balance the different processes and some extensively tried to engage with external actors or customers. Despite the strong utilization of informal learning processes of the DUI mode, nearly all firms complemented their DUI processes with some form of codified knowledge or applied the STI mode of innovation to generate codified knowledge (Alhusen and Bennat, 2020). The choice of the innovation mode and the respective activity seems to be driven by circumstances, firm-related or individual characteristics in our sample. One regional innovation consultant highlighted this fact explicitly: *"There is certainly the company owner, who, by whatever means, is motivated to say, now I am changing things. But there are also, I would say, the executives, the engineers who might come to the company and bring ideas with them and say, man, let's think along these lines or try things. Well, there is certainly not only one possibility*" (C23). Overall, we observe a large variety in our sample with respect to the different DUI processes which gives us confidence that we are able to capture an exhaustive range of possible learning processes and do not observe a subset of group-specific phenomena.

The insights for the three doing, using and interacting learning processes were assessed in a process of inductive and deductive reasoning to create a finer-grained categorization of distinct processes. We separate six distinct categories for learning-by-doing, where we further separate two kinds of doing-related processes, namely learning-by-doing in the sense of Arrow (1962), as well as a learning-by-doing process that relies on internal interacting and knowledge flows in the production process in team settings. We derive three categories for learning-by-using that capture the learning processes via exchange with users of the products and services that the firm offers. Furthermore, six categories emerge for learning-by-interacting from the data and aggregate the exchange with different kinds of external actors, such as competitors or suppliers. The frequency of the different categories substantially varies between the different firms, but we abstain from assigning them a degree of importance since we are interested in the whole range of possible learning processes.

Based on the different categories, we derive indicators for measuring the learning processes in the different categories. The understanding gained of the different processes from the interviews and a triangulation with the existing literature provides a solid foundation of the learning processes, which flows of knowledge exist and how they are facilitated in the firm. Thereby, the interplay between the flows of knowledge and the relevance of respective facilitators were especially emphasized by our interviewees, as one put it: *"company needs persons […] who have to*

understand what the company can do, they have to understand in which direction the company can develop and they have to understand very precisely what the customers and the competition are doing. […] These people in key positions within the company must all be extremely well informed" (C31). We therefore systematize our indicators into measures of flows of knowledge or measures of facilitators along our framework form Section 2. We discuss the different categories in the following separately for the doing, using and interacting process and propose our indicators for measuring such processes. The final set of indicators along with the suggested formulation for items is presented in the Supplementary Material O4.

4.2. Learning-by-doing indicators

Learning takes place as a by-product of carrying out an activity and knowledge accumulates over time. Within a firm, these learning processes are summarized as learning-by-doing and they constitute different flows of knowledge, originating in performing certain tasks and the usage of required products and tools to fulfill these tasks. This knowledge is directly used to improve the task itself or its outcome, and it is essential for the innovative performance of the firm (Arrow, 1962; Thompson, 2010). Our interviews revealed a multitude of different learning processes within the firm. A first set of processes relates directly to a task or a production process and how the production process can be improved or new solutions implemented. Within these classical learning-by-doing activities, we emphasize processes that pronounce knowledge embedded in equipment and employees. The second set of processes focuses on interaction within the firm, especially between the employees in the production process. This learning-by-internal-interaction and related knowledge flows among employees are based on a firm's routines and structures. Internal interacting has previously been identified with measures of formal group compositions (Jensen *et al.*, 2007; Herstad and Brekke, 2012), structures and tools that foster innovative activities and idea selection (Fu *et al.*, 2013) and formal innovation management systems (Rammer *et al.*, 2009; Parrilli and Elola, 2012; Apanasovich *et al.*, 2017). However, our interviews reveal that especially informal practices are decisive for the relevant knowledge exchange to improve production processes, as one CEO highlighted: "*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*" (F29).

Based on our interviews, we propose six categories of learning processes: three for the classical learning-by-doing activities and three for the learning-by-internal-interaction. For each category, we propose several indicators that characterize the measured phenomenon as a knowledge flow or facilitator. Table 2 provides a summary of these categories and indicators, along with their measurement type.

One key flow of knowledge is related to the **employed technology** (category 1) in the firm. New technology embodies knowledge from other sectors (von Hippel and Tyre, 1995) and firms adjust technologies to their needs (Robertson and Patel, 2007). Firms learn from new developments by either *introducing new equipment* (indicator 1) or *improving existing equipment* (indicator 2). The introduction and improvement of machinery, hardware or software allows firms across industries to create new products and services, increase their variety or quality of products and services, by exploiting the full range of possibilities offered by the new technology. A common example is an increase in capacities through improved machinery. In accordance with the literature on learning-by-doing (Thompson, 2010; Levitt *et al.*, 2013), improving existing equipment is described as an everyday task to extend the limits of the existing equipment: "*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). Both indicators can capture knowledge flows that enter or are generated in the production side and can substantially contribute to innovative output.

Table 2
Summary of the learning-by-doing and learning-by-internal-interacting indicators.

Category	Indicator	Kind of measurement
1. Employed technology	1. New technology introduction	Knowledge flow
	2. Current technology improvement	Knowledge flow
2. Training	3. Training regarding general qualification	Knowledge flow
	4. Training regarding firm-specific qualification	Knowledge flow
3. Trial-and-error learning	5. Scope for trial-and-error learning	Facilitator
	6. Use of experience	Knowledge flow
	7. Creativity in the workplace	Facilitator
4. Informal contacts and firm-internal relations	8. Maintaining informal contacts within the firm	Knowledge flow
	9. Mutual support among employees	Knowledge flow
	10. Maintaining good relations within the firm	Facilitator
	11. Learning by observing	Knowledge flow
5. Mechanisms of knowledge exchange	12. Regular team meetings	Facilitator
	13. Knowledge exchange among employees with different tasks	Knowledge flow
	14. Open communication culture	Facilitator
6. Human resource management tools	15. Delegation and degree of autonomy	Facilitator
	16. Integration of functions	Facilitator
	17. Monetary incentives for idea disclosure	Facilitator
	18. Knowledge management	Facilitator
	19. Idea management	Facilitator

Another key flow of knowledge is **training** (category 2), which increases the available stock of knowledge that is embedded in the employees. Improving the abilities of the employees via sharing work experiences, tacit knowledge training and the effective exchange of this knowledge reflects an important flow of knowledge improving the innovative activity of a firm. The positive impact of training on firm-level innovativeness has been identified in a multitude of studies (Bauernschuster *et al.*, 2009; Amara *et al.*, 2008; Apanasovich *et al.*, 2017). The differentiation and its relevance of general and specific training as important means for firms to increase their human capital was first described by Becker (1962). Accordingly, we differentiate training into *general training* (indicator 3) and *firm-specific training* (indicator 4), 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 specified to the tasks in the firm at hand. Training usually leads to new knowledge flows and the benefits are long lasting and can be substantial, as one CEO highlighted: *"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. […] 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). Especially specific training was seen as important by our interviewees in cases when employees had reached the boundaries of their competences or the technological frontier had shifted.

According to our findings, **trial-and-error learning** (category 3) that relies on the application of tacit knowledge is often found at the center of informal innovation activities. A central issue is the role of experience-based know-how for innovation as a part of organizational

learning and how knowledge flows at a variety of levels (Howells, 1996). Especially experienced-based know-how and on-the-job learning are important parts of trial-and-error learning (Jensen *et al.*, 2007; Isaksen and Karlsen, 2010). This category captures knowledge flows as employees transfer tacit knowledge through experimentation and develop capacities to apply previous solutions to new but similar problems. One CEO described this process as follows: *"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 [the employee] has to get back to the problem. He has to find the analogies between the new and the 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. […] and when you have done it for twenty times, you will do it better than the first time […] due to your experience"* (F28). Thus, the accumulation of tacit knowledge enables long-term problem-solving behavior, which constitutes the *scope for trial-and-error learning* (indicator 5). Without the opportunity to try something new without being blamed if it fails, employees are unwilling to implement new ideas. However, without the existence and possibility to transfer gained knowledge and make *use of experience* (indicator 6) from former problem solutions to current problems, the potential for knowledge flows is limited. One potential facilitator of this experience is the *creativity in the workplace* (indicator 7) of the employees, which can direct the existing knowledge to solve current problems.

Many firm-internal learning processes take place in team settings. This informal knowledge exchange, problem-solving and the application of experience-based knowledge is more often based on **informal contacts and firm-internal relations** (category 4). Informal processes of learning and knowledge exchange were mentioned by Jensen *et al.* (2007) and highlighted by qualitative studies on DUI mode innovation (Isaksen and Karlsen, 2010; Trippl, 2011; Aslesen and Pettersen, 2017), while some measurement approaches have already been proposed (e.g. Rammer *et al.*, 2009; Thomä, 2017; Thomä and Zimmermann, 2020). In our interviews, it was highlighted that more experienced team members and employees share their knowledge through an *informal exchange of knowledge in the workplace* (indicator 8) and the *mutual support among employees* (indicator 9) while good *internal relations among employees within the firm* (indicator 10) facilitate and strengthen these flows of knowledge. Experience is accumulated by *observing more experienced colleagues* (indicator 11), which can also be found institutionalized in firms, as an CEO told us: *"the employees we are hiring now and who do not have the training to be a precision optician, they will spend the first six months to at least one year with a good, trained precision optician who will pass on his knowledge as far as possible …"* (F48). The characteristics and the intensity of this informal exchange of information and knowledge in the firm is key for its innovative activity and a central part of learning-by-doing.

Beside informal contacts, firms also establish formal **mechanisms of knowledge exchange** (category 5). One example is regular team meetings such as quality circles or a continuous improvement process, which describe regular meetings among team members to discuss quality-related problems and solutions. Quality circles were not explicitly 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 implicitly. Research on innovation modes has also emphasized cross-functional integration of teams horizontally as well as vertically (Jensen *et al.*, 2007; Parrilli and Elola, 2012; Apanasovich *et al.*, 2017). Moreover, formal mechanisms to collect employee suggestions have already received attention in the DUI literature (Jensen *et al.*, 2007; Parrilli and Elola, 2012; Nunes and Lopes, 2015). This includes institutionalized *regular team meetings* (indicator 12) to discuss novelty-related problems, where regular meetings per se is regarded as a facilitator of knowledge flows among employees. However, many problems are not solved by single employees with a specific specialization but rather require *knowledge exchange among employees with different tasks* (indicator 13). The interplay of these factors was described by one CEO as follows: "*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 did not work. So, what concerns the production process and purchasing and also where things have not worked out, right at the device and then this is implemented right away"* (F16). However, this only works when an *open communication culture* (indicator 14) is implemented in the firm, as highlighted in multiple interviews.

A central aspect in managing the knowledge flows in a firm and the interaction of employees is **human resource management (HRM) tools** (category 6). These facilitators strengthen the knowledge flows through formal mechanisms of knowledge exchange and accumulation. HRM practices usually start to exist in medium-sized enterprises where the flow of knowledge is inhibited and new facilitators for knowledge flows are needed. Central to the management of the knowledge flow is the *delegation and degree of autonomy* (indicator 15) that a functioning HRM should facilitate. Furthermore, capturing the *integration of functions* (indicator 16) to reduce departmental barriers and increase interaction across functional boundaries is an important aspect that was mentioned especially in larger firms. Furthermore, the use of *monetary incentives for idea disclosure* (indicator 17) was mentioned as having an effect on sharing knowledge and ideas, since reward systems strengthen the incentive to communicate new ideas (Apanasovich *et al.*, 2017; Thomä, 2017). Finally, the use of *knowledge management* (indicator 18) and *idea management* (indicator 19) systems seems to capture different facilitating aspects that a firm can use to strengthen internal knowledge flows and thereby its innovative potential. One CEO highlighted the importance of collecting information about product development and further innovations in a central system: *"We are currently in the process of making our so-called knowledge database more perfect. So, if we have attended lectures or presentation somewhere, we archive them now so that they can be retrieved. Also, the results of the test productions are there, and the whole thing must now of course […] be constantly developed further"* (F40).

4.3. Learning-by-using indicators

Learning-by-using describes processes in which intermediate or end users of a product or process share their experience, modifications or redesigns with the original producer so that the product can be improved or extended, or new products can be developed (Rosenberg, 1982). Therefore, learning-by-using encompasses flows of knowledge that can reach the firm in various ways. For instance, customers can articulate a demand for a solution that contains either a precise specification that the firm can use to provide an innovative solution or no specifications at all, where the firm has to search for a suitable solution given the direction indicated by the user. In our interviews, firms often described an iterative process where products are developed or improved in multiple rounds through feedback loops with customers: "*This means that we don't build a series that we can then test for years, but rather we build the number one device directly, which is actually the prototype that goes to the customer. And then, that's the problem of the first customer, but he also has a device that he would like to have, so he can collect what doesn't work there. Then we fix it, even at the customer's site, and change it for the other devices as well"* (F16). These feedback loops most often comprise personal interaction and meetings in person, where knowledge and experience are exchanged within and outside of the firms. Here, firms need to understand what drives customer demand to capture an image of what kind of innovative solutions might be required and channel the knowledge within the firm to the appropriate actors.

Based on our interviews, we aggregate the processes of learning-by-using for innovative activity in three categories, which comprises several knowledge flows and facilitators. Table 3 summarizes the three different categories and the respective indicators.

Cooperation with customers (category 7) is central for learning-by-

Table 3
Summary of the learning-by-using indicators.

Category	Indicator	Kind of measurement
7. Cooperation with customers	20. Thematic field of cooperation with customers	Knowledge flow
	21. Intensity of customer cooperation/interaction	Knowledge flow
	22. Customer innovativeness	Knowledge flow
	23. Customer technological know-how	Knowledge flow
	24. Duration of customer contact	Knowledge flow
8. Customer contact	25. Organizational area of cooperation with customers	Facilitator
	26. Active request for feedback	Facilitator
	27. Use of customer support	Facilitator
	28. Use of social media	Facilitator
9. Product specification	29. Customized products	Facilitator
	30. Additional products and services	Facilitator
	31. Complementary products or services	Facilitator
	32. Customer involvement	Knowledge flow

using and it captures the flows of knowledge that reaches the firm. The importance of customer cooperation has already been assessed (e.g. Gruner and Homburg, 2000), but our interviews reveal a much more nuanced relevance of the flow of knowledge and its preconditions: *"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). Reflecting the lessons learned during our interviews and combining it with findings by (Gruner and Homburg, 2000) and others, we grouped several indicators within this category. It starts with the *field of cooperation* (indicator 20) to elaborate the thematic and functional content of the knowledge flows from cooperation with customers. This allows identifying the different types of knowledge or new ideas, as well as the associated types of innovative output that could be generated from the knowledge. The respective *intensity of cooperation or interaction* (indicator 21) allows a better assessment of the knowledge flow and the extent of knowledge exchange. The intensity can range from a brief information about a potential improvement to a joint development of prototypes or products. In addition to these measurements, customer characteristics such as the *customer's innovativeness* (indicator 22) or the *customer's technological know-how* (indicator 23) can play an important role for the intensity and scope of the knowledge flow (e.g. Gruner and Homburg, 2000). Our interviews reveal that more innovative customers ask for more innovative solutions, whereby the more pronounced their technological understanding or knowledge, the more valuable the related learning processes are: *"[…] we often have cases where a customer approaches us and says he has a challenge. Or I might say he has a problem and he's looking for a solution, but I don't know if there is a solution. […] a developer [the customer], has some kind of design but doesn't know whether it can be produced, and we look around with our technologists: Is that even possible? If it is not yet established […] maybe we could set up a small test series ourselves and have a look if it is manufacturable? And then try to optimize it in consultation with the customer […]"* (F39). Finally, the *duration of cooperation with customers* (indicator 24) plays an important role for the quality and quantity of knowledge flows. The willingness to share knowledge increases with a greater mutual understanding and trust among the users and the firm, which establishes over time. It increases the effective flow of knowledge due to reduced efforts for mutual understanding (how things are said) (Mohr and Bitner, 1991), while the scope or intensity of the knowledge flow (which things are said) increase since customers are more willing to share sensitive information.

Different kinds of **contact points with customers** (category 8) represent a set of facilitators that need to be in place to absorb and integrate the flows of knowledge. Since firms' contact points with customers often have other primary functional tasks than capturing innovation-relevant knowledge, additional functions or activities of these facilitators are required to ensure that the innovative knowledge is identified and transferred to the appropriate place within the firm. First, regarding the *organizational area of cooperation with customers* (indicator 25), different functional units such as procurement, sales, complaints and quality departments, marketing and others need to be able to capture the knowledge from customers and redirect it to the suitable recipient inside the firm: *"Well, anyone who has customer contact can actually record it [the innovative idea]. Well, that's the customer service at our company. Customer Service is the area that actually has the most customer contact besides the sales staff through order acceptance and processing. So, I would say, it's the sales department. One is Customer Service, and the other is marketing, right? So, I'd say that's where wishes and innovation ideas are filtered. And then it is discussed internally and then comes to the people in the company, either to our development engineers or, yes, it depends on what kind of topic it is, it is then forwarded to the appropriate people in charge, and always directly. So, actually, it is passed on directly to the responsible experts" (F7)*. If these facilitators gather additional information, they need supplementary routines to transfer this specific knowledge so that it can be used for innovative purposes. The *active request for feedback* from customers (indicator 26) as well as the *use of customer support* (indicator 27) are similarly key facilitators to acquire knowledge from customers, since they are classically used by firms to identify problems and improve their own products and services (van der Heijden *et al.*, 2013). The firms implement these facilitators in different ways, for example, one CEO states: *"We have a few trade 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 [actual problems with the products]. And that's where the new products are presented"* (F35). Besides these face to face channels of communication, Bertschek and Kesler (2017) show that interaction on *social media* (indicator 28) becomes more important to source knowledge and ideas from customers, which is confirmed in our interviews by the statement that *"[…] simply to be in direct contact with the customer via social media channels"* (F10) generates new knowledge for the firms. Even though this is usually related to marketing efforts, functioning facilitators needs to be in place to collect, structure and direct the knowledge from a broader customer base to the relevant actors within the firm.

Another possibility of how customer demand can result in new or improved products and services is offered by meeting the individual customer **product specifications** (category 9): "*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). If facilitators receive and understand changes in customer demands and suggest possible alterations or new products, the firm can innovate accordingly (Holtskog, 2017). Depending on the respective product specifications, the set of facilitators involved as well as the related knowledge flows leading to innovation can differ. The more specific that a product is, the more often that the firms describe themselves as "*problem-solvers*" and their *customized products* (indicator 29) represent customer-specific solutions that cannot be produced on a large scale. In addition, firms understanding the customers' demands have started to offer *additional products and services* (indicator 30) related to their core product/service, as well as *complimentary products and services* (indicator 31) related to their main products (Isaksen and Karlsen, 2010). One CEO stated that along their core products, "*[…] in addition, we have mostly so-called quality agreements or quality insurance agreements with the customers, in which is regulated what is customer-specific […]*" (F28). Firms need to have these facilitators in place to transform the customers' demands into new

products and services. Furthermore, *customer involvement* (indicator 32) in the product specifications is thereby an important knowledge flow that can help in a systematic search for innovative solutions.

4.4. Learning-by-interacting indicators

Learning-by-interacting encompasses knowledge exchange with firm-external actors besides customers. Several aspects of these relationships have already been assessed. 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 suppliers, competitors, firms in other sectors and consultancies (Jensen *et al.*, 2007; Chen *et al.*, 2011; Fitjar and Rodríguez-Pose, 2013; González-Pernía *et al.*, 2015; Apanasovich *et al.*, 2017; Haus-Reve *et al.*, 2019; Parrilli *et al.*, 2020). Only more recent studies have investigated industrial associations or trade fairs (Marzucchi and Montresor, 2017; Thomä and Zimmermann, 2020; Parrilli *et al.*, 2020). In our interviews, these actors are frequently mentioned as sources of new knowledge and partners in innovative activity. As one innovation consultant stated: "*Do I [the SMEs he is consulting] open myself up to the outside world? This means that I give other partners an insight into what I imagine and what I am planning at the moment. To get the benefit that these others say something by themselves without getting into any patent disputes. And then just to realize: 'Man, we can complement each other in some way*'" (C13). Our interviews also reveal the necessary facilitators who need to be present to capture and augment the knowledge flows and help to translate them into innovative outcomes.

We categorize the different knowledge flows and the related facilitators along the different kinds of actors with which firms can engage. This results in six categories with corresponding indicators, which are summarized in Table 4.

A large share of firms utilizes knowledge flows from **interactions with suppliers** (category 10). Suppliers can provide information about specifications of the supplies, such as material characteristics or functional scope which are relevant when developing new or improved products. These knowledge flows can increase a firm's innovative activities due to access to specific know-how or knowledge about new technological developments as one interviewee highlighted: *"Well, first of all through new and innovative products and applications of the respective products. That is the main aspect"* (F30). Central here is the *innovation cooperation with suppliers* (indicator 33) as a core knowledge flow. This central interaction with suppliers was already mentioned as relevant for innovative activity by Jensen *et al.* (2007) and Isaksen and Trippl (2017). Here, a firm relies on a *supplier's competences* (indicator 34) to gain relevant knowledge about the, e.g., material supplied and how it would suit the product requirements. The choice of a competent supplier facilitates the potential knowledge flow because suppliers can offer advice on how to handle new product development. However, knowledge exchange is also facilitated by the *supplier relationship* (indicator 35) that the firm has and how interaction is valued, whereby a more trustful relationship allows for a more detailed and frequent exchange of knowledge.

Table 4
Summary of the learning-by-interacting indicators.

Category	Indicator	Kind of measurement
10. Interaction with supplier	33. Innovation cooperation with suppliers	Knowledge flow
	34. Supplier's competences	Facilitator
	35. Supplier relationship	Facilitator
11. Interaction with competitors	36. Competitor relationship	Knowledge flow
	37. Competitive pressure	Facilitator
12. Interaction with intra-sectoral firms	38. Innovation cooperation within the sector	Knowledge flow
	39. Intra-sectoral relationship	Facilitator
13. Interaction with extra-sectoral firms	40. Innovation cooperation across sectors	Knowledge flow
	41. Extra-industry relationship	Facilitator
14. Interaction with consultancies and public institutions	42. Supporting innovation cooperation	Knowledge flow
	43. Relation with consultancies	Facilitator
	44. Collaboration financing	Facilitator
	45. Importance of innovation awards	Facilitator
15. Trade associations and networks	46. Participation in network events	Knowledge flow
	47. Importance of network relations	Facilitator

Interaction with competitors (category 11) is another way to acquire knowledge, although it is challenging and rare, as cooperation is described as a potential risk for the loss of firm-internal know-how. Contrary to Jensen *et al.* (2007), competitor collaboration was less commonly mentioned in our interviews. Fitjar and Rodríguez-Pose (2013) showed that collaboration with competitors even has a detrimental effect on innovation activities. Cooperation with competitors therefore only occurs where it does not risk a firm's specific know-how. However, it takes place and some interviewees explained that a *competitor relationship* (indicator 36) includes indirect knowledge flows via observing competitors and the possibility to learn from their success and failures. One CEO put it bluntly: *"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 do not want to have on our products"* (F29). Furthermore, *competitive pressure* (indicator 37) was mentioned as part of the motivation for innovation activities, which facilitates collecting information about competitors and their competencies and innovating accordingly.

Contrary to relationships with competitors, there is **interaction with intra-sectoral firms** (category 12). These are often firms that do not share the same (regional) market and therefore direct competition is not a problem for either firm. One 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. For example, one CEO stated that *"extra-regional [collaboration] 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). Accessing such knowledge flows resulting from such cooperation had not previously been mentioned in the literature and measuring the flow of knowledge from such *innovation cooperation within the sector* (indicator 38) as well as the perceived importance of an *intra-industry relationship* (indicator 39) as important facilitators for knowledge flows are important.

The **interaction with extra-sectoral firms** (category 13) can provide knowledge flows that might be unrelated to the firm's knowledge base but can lead to a higher combinatorial impact. For example, Bennat and Sternberg (2020) argue that interactive learning processes tend to cross sectoral boundaries and allow firms to tap into different kinds of knowledge. An interaction with actors from other sectors offers access to partners' internal know-how and solutions that firms from the same sector would usually not reveal, such as knowledge about technology and new developments: *"Also, [important for innovation are] 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 our firm"* (F19). These interactions comprise knowledge flows for implementing ideas within the firm. In accordance

with previous interaction partners, the *innovation cooperation across sectors* (indicator 40) as well as the perceived importance of an *extra--industry relationship* (indicator 41) are respective facilitators.

Interactions with consultancies and public institutions (category 14) are a further source for flows of knowledge. Especially regional policy-makers are engaged in promoting and supporting regional interactive learning and cooperation (Martin *et al.*, 2011). This also reaches the firms and establishes fertile ground for further innovations, as one CEO described: *"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 circle, where we discuss these developments. And there, I would argue, we start to be innovative, ok? However, we do not plan innovations there in a traditional sense"* (F8). The interviews revealed different forms of knowledge flows related to the work of consultants. They advise firms by *supporting innovation cooperation* (indicator 42) to establish and improve the firm's internal innovation processes, by both bringing new ideas into the firm as well as reorganizing firm-internal structures to improve knowledge flows within the firm. However, not all interactions with consultancies are valued as being helpful, and thus the *relationship with consultancies* (indicator 43) is an important facilitator that needs to work well to allow firms to benefit from this kind of the external support. The interviewees revealed that most often consultancies establish connections with other actors, supply firms with firm-external *collaboration funding* (indicator 44) to conduct such activity and increase their visibility through hosting *innovation awards* (indicator 45) and related network events, which facilitate the access to external knowledge and influence the innovation process.

Trade associations and networks (category 15) were frequently named as sources to gain external knowledge by the interviewed firms. One CEO explained their importance: *"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 do not leave it to chance that these technologies reach us at some point"* (F7). Such *participation in network events* (indicator 46) is used to reach out to different actors to tap into knowledge that then flows into the firm. However, the *importance of network relations* (indicator 47) needs to be understood by the firm to facilitate such knowledge flows. Innovative activity is only increased if firms actively use these platforms for knowledge flows and interact with other firms from the same or different industries. Especially the informal settings in which the firm can acquire new knowledge is challenging to handle (Isaksen and Trippl, 2017). Ultimately, the firms' attitude towards those networks and trade associations facilitates or limits the respective knowledge flows.

4.5. Discussion

Our analysis of the qualitative interviews reveals that the fifteen different categories that we derived in a combination of deductive and inductive reasoning provide insights into a wide range of DUI mode learning processes. Each of these processes was deemed important for the innovative activity that the firms conducted, and they extend the literature on DUI mode innovation activities. Figure 2 summarizes the different measurement categories in the conceptual scheme proposed in Section 2. The six learning-by-doing processes allow extending the current measurement of firm-internal processes for innovative activity to account for the accumulation of knowledge from repeated production activities and the related environment, as well as the exchange of knowledge and the joint process of problem-solving in teams. Especially the latter point has previously been neglected in the literature on DUI mode innovation activities. The three learning-by-using categories allow measuring the relationship with customers and their contribution to the knowledge accumulation process. This process is quite diverse and complex (Cantner et al., 2021), and has not been treated in a nuanced manner empirically. Finally, the learning-by-interacting categories span the whole set of potential partners and provide a better picture of the

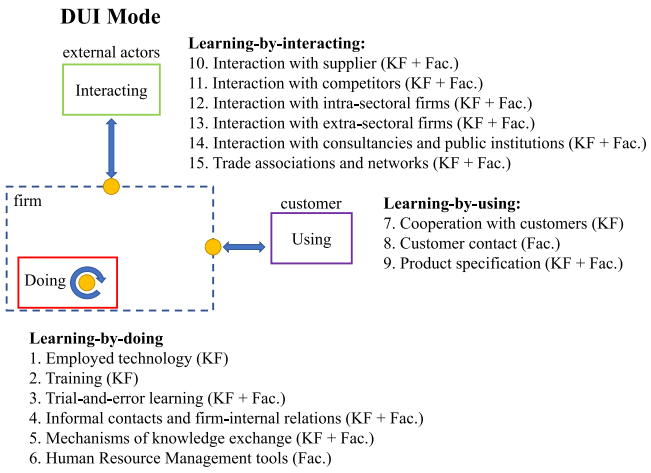

Figure 2. DUI mode learning processes and respective measurement categories.
Note: *KF* indicates categories that contain indicators for knowledge flows. *Fac.* indicates categories that contain indicators for facilitators.

different kinds of relationships and their importance for learning and innovation. Even though learning-by-interacting is the most frequent type of activity analyzed in the DUI stream of research, a full assessment of the whole scope is absent so far. Therefore, the categories provided complement and unify previously diverse approaches to measure such activity.

The proposed indicators to measure the learning processes holistically capture the different DUI mode activities for quantitative assessments. Thereby, the separation into knowledge flows and facilitators guides the measurement of what kind of information is transmitted and from where or at which point in the firm. Several of these indicators have already been proposed or used in some form in previous studies on innovation measurements. From the total of 47 indicators that we propose, 43% have been newly formulated based on our interviews, 25% have been adapted based on a more detailed understanding provided by the interviewees and 32% have been adopted from prior surveys without adaptation. Some additional indicators that have been emphasized in previous studies are irrelevant within our sample of interviews, and some have been changed or adapted based on more detailed insights by the interviewees. Such indicators were adapted to the description and understanding of our interviewees. For example, regarding learning-by-doing in team settings, our adaptations have the advantage that the indicators are not confined to a specific management practice, such as quality circles, lean management, or agile project management with scrum (Heij *et al.*, 2020; Vaccaro *et al.*, 2012), but rather they describe the idea behind the management practice in general and allow for a more inclusive assessment. Moreover, previous indicators for learning-by-using were ill-defined in some cases and capture learning-by-doing relevant activities, or they were not truly in line with the idea of learning-by-using as proposed by Rosenberg (1982).

The overall set of indicators aims to capture DUI mode learning holistically, but we observed relative differences between the firms in our interviews. In previous literature, clusters of firms according to their use of certain DUI-activities were derived (e.g. Jensen et al., 2007; Nunes and Lopes 2015; Thomä 2017; Thomä and Zimmermann, 2020). For example, the cluster analysis by Thomä and Zimmermann (2020) reveals that a customer-oriented DUI firms strongly focuses on learning from internal interaction and market knowledge, i.e. interactive learning with customers, while supplier-dependent DUI firms in turn neglects learning from these factors and instead focuses on application-oriented industry knowledge. However, these analyses were conducted with a few indicators, which limit a more fine-grained assessment of the differences in relevance of the DUI-processes. In our

interviews, we observe that firms focus on specific learning processes based on their sectoral origin. For example, in the East-Thuringian optics industry firms produce highly specialized products and utilized using-processes extensively and co-created new products with their customers (see Cantner et al., 2021 for details). Firms in other industries rely on doing activities only to increase their production capacity or reduce costs. Such patterns are in line with the Pavitt-Taxonomy which shows that the sources of flows of knowledge vary according to the sector of utilization (Pavitt, 1984; Bogliacino and Pianta, 2016). Our interviews revealed these sectoral differences in the use of the DUI-mode and can serve as a starting point to better understand the utilization of the different learning processes and their relative importance. Thereby, also the question which learning processes substitute each other needs to be addressed. While one can propose that firms rely mainly on the learning processes in line with their sector, an empirical assessment of the complementarity and substitutability of different DUI-processes is absent from the literature.

Besides these DUI mode activities, STI activities also play a non-negligible role in most of the firms that we interviewed. In line with the theoretical measurement concept proposed in Section 2, for such activities several measurement approaches already exist (e.g. Hall and Jaffe, 2018; OECD, 2015, 2018) and our interviewees stated the well-known importance of R&D labs, reliance on codified knowledge and research collaborations with firms, research institutes and customers but provided no further meaningful insights.

In our interviews, the interaction between DUI mode and STI mode activities was mentioned several times (see Alhusen and Bennat, 2020 for details). This is in line with the existing literature (e.g. Jensen *et al.*, 2007; Fitjar and Rodríguez-Pose, 2013; Nunes and Lopes, 2015; Haus--Reve et al., 2019). Integrating the two modes seems to hold particular importance for the firms that also innovate in the STI mode. One interviewee highlighted that *"… of importance is the connection between the R&D [personnel] … and the real practitioners, the department leaders who apply it to the machines. … the distances are short, our R&D engineer is about three times per week in the production facility and our department leaders meet nearly daily with him and they discuss things like 'look, this does not yet work!'"* (F16). The knowledge flows and the facilitators at play to connect the different modes also hold crucial importance. The interplay, especially with the R&D department and production facilities, is at the core of the innovation management literature and several measurement concepts and indicators exist to capture these relationships (Darroch, 2003; Yi, 2009). However, in the existing literature, the joint effect of both modes is measured by an interaction only and most studies point to an additive effect of STI and DUI learning (Jensen et al., 2007; González-Pernía et al., 2015; Parrilli and Heras, 2016; Parrilli et al., 2020). Only Haus-Reve et al., (2019) show that learning by interacting, measured by supply chain collaborations, and STI interaction substitute each other. Their results indicate that external collaborations seem to substitute each other; thus, "more of all" might not be a good strategy for generating innovative outcomes.

5. Conclusion

We propose a new measurement conception to assess DUI mode innovative activity to complement STI mode innovation measurement. In the proposed measurement conception, we have separated the indicators into knowledge flows and facilitators as a starting point to quantify innovative activity. We conducted semi-structured interviews with 49 firm representatives and 32 regional innovation consultants. In conjunction with the existing DUI literature, our qualitative interviews revealed 15 categories of DUI-related learning processes. These categories partly align with previous findings (Apanasovich *et al.*, 2017), while also revealing new learning and knowledge accumulation processes, especially for learning-by-using, which has largely been neglected in previous research (Cantner et al., 2021). In sum, we have derived 47 ready-to-use indicators for these 15 categories, which capture the underlying knowledge flows and the intensity of the relevant facilitators required to enable or intensify the flows of knowledge to reach their economic application in the firm. Our new set of indicators can be used for quantitative assessments to enrich the understanding of DUI mode innovative activity and inform policy-makers on where and how to quantify and potentially support such activities.

Our suggested measurement approach as well as the derived indicators contribute to the theoretical literature on measuring innovative activity for the DUI mode in particular (Jensen *et al.*, 2007; Apanasovich, 2016), and innovative activity in general. The separation to measure innovative activity in terms of knowledge flows and facilitators allows for a better understanding of how knowledge is generated, as well as how it is collected, augmented and distributed within and between organizational units. Consequently, a more fine-grained assessment of how firms acquire new knowledge and use it internally can be established. With respect to the DUI literature in particular, we advance the contribution of Jensen *et al.* (2007) by defining, disentangling and analyzing learning processes related to the DUI mode of innovation. These learning processes – especially the internal interacting in the firm, but also the processes concerning how firms learn from customers and the potential to measure such interactions – also contribute to a better theoretical understanding of the innovation process. This especially holds true for the joint presence of DUI- and STI-related activity in a firm, where previous assessments fall short in providing a holistic assessment of DUI activity in conjunction with STI measurement, albeit which is required to identify potential points of complementarity or substitutability.

Our methodological approach of conducting and combining in-depth interviews with firms and regional innovation consultants to derive new innovation measures can be applied to assess other potential measurement problems. The triangulation of the different perspectives from the interviews and previous findings in the literature allows deriving a clearer picture of the underlying process and helps to formulate respective measurement approaches. Based on our derived indicators and after thorough testing and adjusting, one could think of expanding the coverage of the OECD Frascati and OECD Oslo Manual – as well as innovation surveys in general – by including DUI mode activities. Such a holistic measurement approach for innovative activity would be able to avoid a bias towards formal R&D efforts. Our provided set of ready-to-use indicators in the Supplementary Material for implementation in such surveys can be taken as the starting point of such an extension.

The detailed assessment of DUI mode innovative activity and the resulting measurement approach have several implications for policy-makers. First, policy-makers need to extend their understanding and information on DUI mode innovative activities to target governmental support accordingly, since most support is targeted to support STI activities (e.g. R&D tax incentives). Second, we suggest that based on the measurement approach provided, larger-scale innovation surveys should be conducted to collect relevant information to develop DUI mode-related policy support. Complementary to the STI assessment in the Community Innovation Survey (CIS), or jointly with the CIS, a repeated survey to assess DUI mode activities should be installed. The respective results would be relevant to understand innovation-related phenomena such as the declining innovator rate, which is currently only captured by STI-related innovative activity. Third, better-informed policy-makers can not only implement instruments to enhance DUI mode activity but also use the information to support structural policy to support innovatively-backward regions that presumably have lower barriers to engage in DUI mode innovative activity than STI mode activity. Finally, we suggest that these large-scale surveys should also consider the territorial specificities of innovation processes to encourage comparisons across sub-national regions.

The presented findings can not only guide policy-makers, but they also have implications for management. The interviews revealed that many firms utilized only a limited fraction of the wide range of DUI mode learning processes. Especially external knowledge flows were

neglected in many cases, which could be harnessed more systematically. Also, the necessary facilitators need to be in place to utilize knowledge flows. Especially in SMEs, such facilitators are easily neglected and firms should have the appropriate facilitators in place. For this, firms need to think about necessary organizational changes and build up the required absorptive capacity (Cohen and Levinthal, 1990; Som *et al.*, 2015). Our set of knowledge facilitators offers a starting point for a broader, DUI-related set of facilitators that management can implement to improve the absorption and utilization of knowledge flows.

However, our proposed indicators are not without limitations. First, we propose a larger set of items that show relevance in our qualitative interviews, but we do not have information about their quantitative relevance. While testing the proposed indicators empirically is beyond the scope of the current paper, the lack of empirical relevance needs to be addressed in the next step and can limit the application in short surveys. Second, we only provide indicators for DUI mode activity, but not for STI and the interaction of the two modes. Third, some of the proposed items seem to be difficult to capture empirically and they might be unfeasible to measure in large-scale empirical studies because respondents might not have the detailed knowledge. Finally, we relied on SMEs to understand DUI mode processes, but they might not necessarily be the same in large firms and processes can show different behavior or firm-size specific DUI processes might exist.

Further research needs to address some of these limitations but can also utilize the data generated to answer theoretical and policy-relevant questions. The consequential next step is to run a large-scale survey with the proposed items and compare them with established STI measures. This would allow understanding the quantitative relevance and feasibility of the proposed items. With a better understanding of the quantitative relevance, the overall set of indicators should be augmented to remove irrelevant items but also refine and include missing measurements. Thereby, an aggregation of indicators might be necessary, either based on the empirical relevance or via empirical methods of dimension reduction. Based on a refined set of indicators, future research should particularly target the relevance of the indicators for different sectors, as differences are already indicated in the interviews as well as interactions among the DUI indicators but also with STI indicators. Finally, further research should advance the measurement of DUI mode activities for causal inference.

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Appendix

6.1. *Interview guidelines for firm representatives.*

Category	Question
Firm characteristics	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)
New innovations within the last three years	Which novelties have you produced within the last three years (product, process, social, marketing, innovation)?
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?
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?
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?
Knowledge exchange within the firm	How do you exchange knowledge and experience within the firm regarding your production? Do you use heterogeneous teams?
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?
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?
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?
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?
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?

6.2. *Interview guideline for regional innovation consultants.*

Category	Sub-question
Job description/task/role	What does your job description say about promoting innovation in SMEs? (short)
1 Meaning of innovation	How do you define innovation? How do your clients define innovation?
1 Innovative behavior and innovation without R&D	How do SMEs innovate without formal R&D? What processes in SMEs foster innovation?
1 Regional aspect of innovation	Which particular factors favor the capability to innovate in SMEs in our region?

(*continued on next page*)

(*continued*)

	Are there regionally-specific factors that influence the innovation capability of SMEs in our region?
1 Importance of the relation to other firms	How does cooperation with other firms or organizations influence innovation capabilities of SMEs?
1 Importance of experience-based knowledge	What role does experience-based knowledge play in SMEs' innovation processes?
1 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?
1 Economic policy aspects	Which kind of challenges do you face for regional innovation policy to increase innovation activities in SMEs in our region?

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We are thankful to the interviewees for their time and insights provided. This work was supported by the German Federal Ministry of Education and Research, Grant Number 16IFI005. We are grateful to Omar Martin Fieles-Ahmad and Tina Wolf as well as three anonymous reviewers whose comments helped to substantially improve the paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.respol.2021.104214.

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