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From automation to databased business models – digitalization and its links to innovation in small and medium-sized enterprises

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Abstract:

In order to provide a better basis for measuring the complex interplay between digital technologies, competences and innovation, the present paper examines the digitalization-innovation link in small and medium-sized enterprises (SMEs). Starting from a review of the fourth edition of the Oslo Manual, a qualitative content analysis of interview data on innovating German SMEs is conducted to derive a category system that covers the multidimensional relationship between digitalization and firm-level innovation. Its empirical application confirms the heterogeneity of innovating SMEs with regard to digital transformation. While some SMEs are slow to find their way into digitalizing their innovation processes, others have started to use new digital technologies for efficiency reasons in the sense of "doing the same with less", while still others are aligning their entire business model with the requirements of digital environments based on the innovation principle of "doing something new". The paper concludes with implications for innovation measurement, managers, policy and research.

JEL: D22; O31; O32; O33

Keywords: Digitalization; Digital innovation; Innovation measurement; Qualitative content analysis; SMEs

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1. Introduction

Digitalization is expected to have a profound impact on firm-level innovation (Teece 2018; Nambisan et al. 2019; Bogers et al. 2022), which is one reason why supporting small and medium-sized enterprises (SMEs) to use digital technologies is one of the current policy concerns in the context of digital transformation (OECD 2019, 2020). Digitalization changes innovation processes in a variety of ways, leading to a complex interplay between the use of digital technologies, corresponding competences and innovation at the company level, a topic that has only recently entered into the focus of innovation research (e.g. Ciarli et al. 2021; Paula et al. 2022). A better understanding of this multidimensional digitalization-innovation link is crucial; for example, to explain how smaller firms are adapting and recombining digital technologies, know what competences they are using for digital-based innovation, or assess the extent to which digitalization is more of a driver of SME innovation or an innovation outcome in itself.

Several studies have been published on the digitalization behaviour of SMEs (e.g. Fauzi and Sheng 2020; Saura et al. 2021; Soluk and Kammerlander 2021) or specific aspects of the digitalization-innovation link in smaller firms (e.g. Coreynen et al. 2017; Bouwman et al. 2019; Taura and Radicic 2019; Ben Arfi and Hikkerova 2021; Soluk 2022). However, at present, there is no overall picture on the multidimensional aspects of the digitalization-innovation link in SMEs. However, this would be a prerequisite for innovation policy to meet the need of smaller firms for targeted support in coping with the digital transformation.

Measuring the digitalization-innovation link in SMEs therefore provides a vivid example of the general need for developing adequate indicators on the use (or planned use) of new technologies and practices in firms, so that it can be assessed how this influences their innovation activity (Gault 2013). In this regard, the fourth edition of the Oslo Manual (OECD/Eurostat, 2018; in the following: OM 2018) was a milestone. For the first time, a broad variety of digitalization-relevant aspects has been compiled from the perspective of innovation measurement. Numerous indications are given in loose order throughout the OM 2018; for example, on the role of digital technologies in both product and business process innovation, the classification of software development and database activities as potential innovation activities, the key importance of digital competences as a driver of innovation or the relevance of external market factors in triggering digital-based innovation. Thus, in a sense, the OM 2018 is a "real treasure trove" for delving deeper into the interdependencies between digital technologies, corresponding competences and firm-level innovation. However, a review of the OM 2018 on these different links in the relationship between digitalization and innovation as well as its systematic transfer and validation in empirical innovation studies is still missing. Moreover, several relevant main and sub-dimensions of the digitalization-innovation link are not or only partly addressed in the OM 2018, such as the within-firm drivers of digital-based innovation, the impact of external non-market factors or the overall relevance of digital-based innovation activities for the economic performance of companies.

Against this background, this paper explores the question of how digital technologies, competences and innovation are linked in SMEs. The resulting contribution to the literature is a better understanding of the multidimensional role digitalization plays in innovation activity at the company level. To this end, we start our empirical analysis based on a review of the OM 2018 by identifying a first set of potential links between digitalization and firm-level innovation. The system of content categories that we are developing on this basis forms the first step of a qualitative content analysis (QCA) of interview data from a sample of 49 innovating German SMEs. This serves the purpose of empirically validating the category system developed based on the OM 2018 and adjusting or expanding it via inductive reasoning. The result is a differentiated set of thematic areas that depicts the complex relationship between digital technologies, corresponding competences and SME innovation in its various facets. To complete this picture, we examine how these different categories relate to each other and use the derived category system to analyse – in the sense of a basic validity test – which groups of SME innovators can be distinguished in terms of their capability to use digital technologies in their innovation activities.

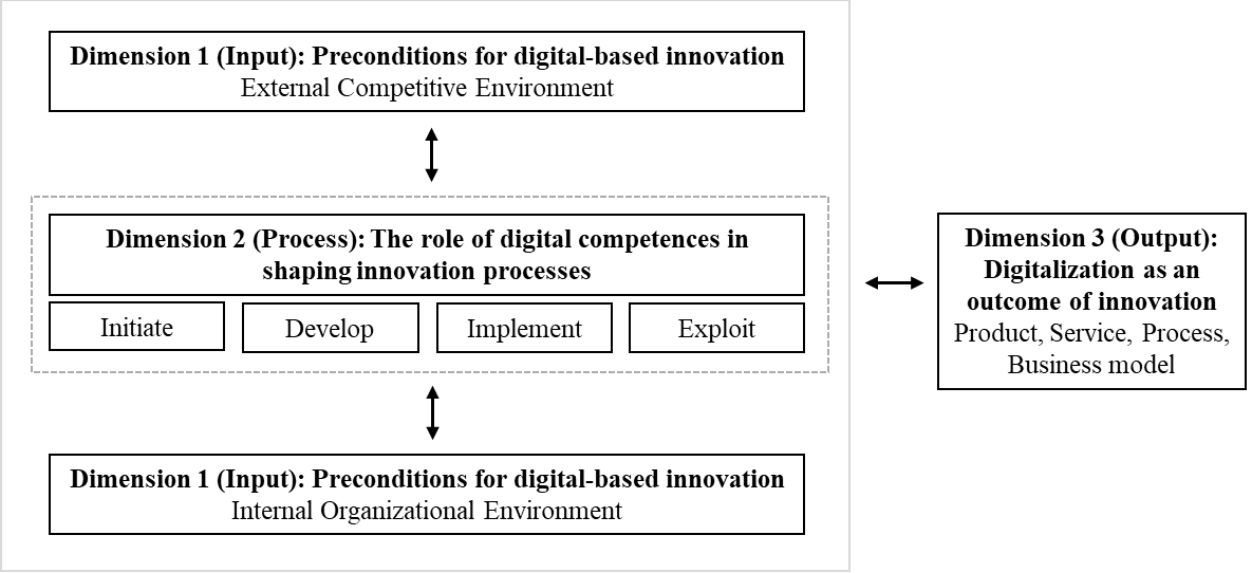
In this way, the results of our paper provide several indications for innovation measurement (for an overview of the literature, see Dziallas and Blind 2019) – either by showing where innovation indicators can be targeted in the future to (quantitatively) measure the digitalization-innovation link at the company level, or, more concretely, where future revisions of the Oslo Manual could start in order to further improve the guidelines for measuring the multidimensional relationship between digitalization and innovation. Our paper can thus help managers, researchers, and policymakers alike who are interested in the role of digitalization in the context of firm-level innovation.

The remainder of this paper is organized as follows. In Section 2, we discuss our theoretical framework of the digitalization-innovation link in SMEs. Section 3 presents our interview data on digitalization activities of innovating SMEs and describes the steps of the QCA. The empirical results are described in sections 4 and 5. Finally, in Section 6 we summarize our results and conclude with implications for innovation measurement, managers, policy and further research.

2. Theoretical background

Based on the Input-Process-Output model developed by Agostini et al. (2020) to describe key aspects of the digitalization-innovation link and the conceptual framework of digital innovation proposed by Kohli and Melville (2019), we assume that the complex interplay between digital technologies, corresponding competences and SME innovation has three basic, interrelated dimensions (Figure 1). The first dimension relates to the input side of innovation by taking into account the fact that a success of digitally driven innovation requires both an organisational willingness to recognise opportunities and an equipment with resources and capabilities (i.e. a conducive internal organizational environment). Digital technologies are dynamic and complex and therefore often entail significant adjustments to a company's organisational culture, decision-making processes, strategies, resources, staffing and communication processes (Agostini et al. 2020). Therefore, due to their limited resource base, SMEs in particular are often only willing to use digital technologies if they consider them necessary in economic terms. Accordingly, they usually carefully weigh the costs and benefits of their use, often approaching the potential efficiency benefits of digitally enabled automation as a first step (Horváth and Szabó 2019; Somohano-Rodríguez et al. 2020; Gartner et al. 2022). Naturally, SME owners play an important role here – either as inhibitors or as promoters of the use of digital technologies. At the same time, employees are of central importance when it comes to making the digital transformation a success in the early phases of the innovation process and thus creating the necessary organisational conditions for digital-based innovation within the firm (Kohli and Melville 2019; Agostini et al. 2020).

Figure 1. Theoretical framework of the digitalization-innovation link in SMEs



Source: Own compilation based on Kohli & Melville (2019) and Agostini et al. (2020)

In addition to these internal drivers, various external factors also are a precondition for digital-based innovation at the company level (i.e. the external competitive environment, see Figure 1). This is particularly important for the digital transformation of innovating SMEs, as smaller firms – due to their resource and capability constraints – are often dependent on impulses from their external environment when it comes to the potential use of digital technologies and practices (Fauzi and Sheng 2020). On the one hand, this refers to basic external conditions such as the industry or the market context of a company, which can determine whether and to what extent digital technologies are required for innovation. On the other hand, the digital transformation influences the way companies and other actors in the innovation system interact and learn with each other. For example, digitalization has changed the nature of external knowledge flows, raising urgent questions; for example, in terms of the appropriability of digital innovation results (Teece 2018; Miric et al. 2019; Butticè et al. 2020) or regarding the interplay of digital technologies and open innovation practices (Brunswicker and Schecter 2019; Shaikh and Levina 2019; Pershina et al. 2019). All these aspects fall within the scope of the external competitive environment as part of the first dimension of the relationship between digitalization and SME innovation.

The second dimension relates to the enabling function of digital competences and related knowledge-based activities throughout the entire innovation process – i.e. from initiation, development and implementation to commercial exploitation of digital-based innovations (Figure 1). It has been shown that dynamic capabilities for digital transformation can have a profound influence on innovation processes in SMEs (Parida and Örtqvist 2015; Cannas 2021; Soluk and Kammerlander 2021). Digital technologies and related competences can enable the creation of new or significantly improved products, processes and business models. Moreover, they promote cooperation, coordination and communication within the company and with external partners such as customers – which opens up a wealth of opportunities for interactive learning. For example, the ability of employees to participate in innovation can be increased through the within-firm spread of digital communication technologies, digitally supported knowledge management and the development of data analysis skills. The resulting demands on the company's internal competence base are correspondingly high (Kohli and Melville 2019; Agostini et al. 2020).

At the same time, the digital components of innovative products or services are often only possible when certain preconditions are met in the company, such as IT resources, digital skills or a digital strategy. This explains, for example, Teirlinck's (2018) finding that there is close link between the internal development of software and in-house R&D activities in certain SMEs. Another example: According to Saura et al. (2021), information from digital databases is relevant for innovating SMEs if they are able to translate their database capabilities into a new digital marketing strategy for product sales. Especially in customer-focused SMEs, collecting and analysing data can help establish a data-driven approach to innovation that enables continuous improvement of products or services based on customer feedback and provides the opportunity to build and maintain close digital-based relationships with customers. For this to succeed, a company must combine the digital and physical aspects of its innovation process as optimally as possible. SMEs in particular, whose innovation mode is relatively strongly based on face-to-face interaction and person-embodied experiential knowledge (Thomä and Zimmermann 2020; Runst and Thomä 2022), therefore face the challenge of maintaining the innovation-promoting balance of human and technology in a digitally supported innovation process when building digital competences.

The third dimension of the digitalization-innovation link (Figure 1) relates to the role of digital technologies for product and process innovation outcomes in SMEs (e.g. Taura and Radicic 2019; Eiteneyer et al. 2019; Ardito et al. 2021; Ben Arfi and Hikkerova 2021) and the implementation of new forms of business models enabled by digital technologies (e.g. Bouwman et al. 2019; Rachinger et al. 2019). On this output side of innovation, two basic types of innovation outcomes can be distinguished from a theoretical point of view (Agostini et al. 2020). One is based on the principle of “doing the same with less”. Here, innovation consists of reducing operating costs through new or significantly improved business processes and protecting a company's profit margin from competitors' price pressure. On the other hand, innovations based on the principle of "doing something new" by using digital technologies to introduce new or significantly improved products or services can increase the company's revenue growth, lead to more lucrative and higher-growth market segments or enhance customer satisfaction. In this context of digital-based product innovation, a continuous reconfiguration of the company's business model is often crucial (e.g. in the context of the use of digital platforms). For SMEs in particular, digital technologies theoretically offer the opportunity not only to benefit from one of these two different types of innovation outcomes, but also to combine the advantages of both underlying principles (Gartner et al. 2022). This is because traditionally, small innovating firms have had to choose between a cost leadership and a differentiation strategy to gain a competitive advantage. Digital technologies now potentially enable SMEs to reduce their costs while simultaneously increasing the value of their market offerings through differentiation.

3. Data and method

3.1 Interview data

Our sample is based on interview data from a previous research project on learning and innovation in SMEs (see Alhusen et al. 2021).[1] During this project, a broad exploratory interview survey was conducted, which addressed, among other things, the digitalization activities of the responding SME innovators. With the help of a semi-structured interview guideline (Table A3 in the appendix), a total of 49 interviews with SME owners and managers took place

[1] The project was entitled “Indicators for the Doing-Using-Interacting-Mode in SMEs (InDUI)”, funded by the German Federal Ministry of Education and Research, Grant Number 16IFI005. We are grateful to have been given the opportunity to analyse the interview data collected during the InDUI project. We would especially like to thank the interviewers, namely Harm Alhusen, Tatjana Bennat, Martin Kalthaus, Stefan Töpfer and Tina Wolf.

between February 2018 and October 2018. In accordance with the commonly-used definition applied by the European Union, an upper threshold of 249 employees was used to identify the survey participants. The average firm size in the interview sample amounts to 49.7 employees, while the interviews lasted 64.9 minutes on average (Table A2).

During the process of data collection, several steps were taken by the corresponding researchers to ensure data validity (from more details, see Alhusen et al. 2021). Since the purpose of the exploratory interview survey was not to collect a representative sample of innovating SMEs but rather the handpicked identification of different relevant cases, a purposive sampling strategy was chosen. Based on extensive web search, suggestions made by regional innovation consultants, the examination of innovation award results and snowball sampling, a number of innovating SMEs were identified. In this context, special care was taken to ensure that SMEs from various industries and business contexts were sampled to account for the heterogeneity of smaller firms in terms of innovation. Moreover, three German regions were selected for the empirical survey (Table A2). In our case, this geographical sample has the advantage that different regional economic and innovation structures are covered. For example, the region of Jena is characterized by manufacturers of optical products that are currently strongly implementing digital transformation processes, while e.g. the SME respondents from the urban area of Hanover often came from the information and communication technology (ICT) sector and thus naturally have a close connection to digitalization. On the other hand, the region of Göttingen has a long tradition in manufacturing meteorological instruments, with digital measurement technology currently being an integral part of product and process automation in corresponding companies. The fact that the heterogeneity of innovating SMEs in terms of sector and company context was taken into account in the previous project when compiling the interview sample therefore has the benefit for us that the role of digital transformation for SME innovation can be very broadly examined.

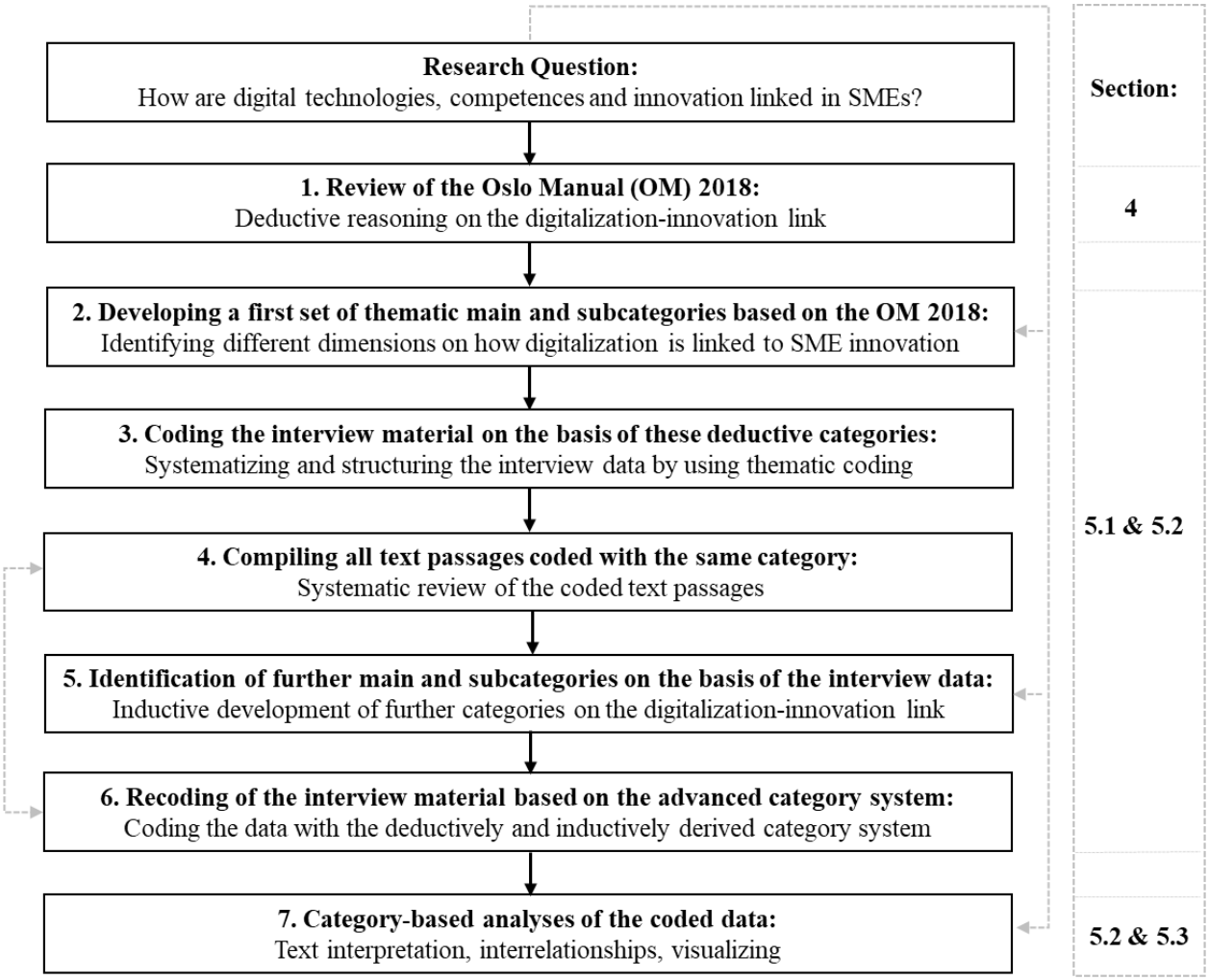
Furthermore, as the former project's primary research interest laid in conducting an exploratory investigation into the innovation activities and learning processes of the sampled SMEs, the interview guideline was only used to roughly structure an interview talk to enable a high degree of flexibility and openness in collecting information from respondents. Because of this, the topic of digitalization came up at various points in the interviews – either by the interviewees themselves or through specific queries by the interviewers regarding certain digitalization aspects relevant to innovation.

The willingness of respondents to provide information was supported by promising anonymity for all interviewees. For this reason, each respondent is assigned a unique number, on the scale I1 to I49 (Table A2). Moreover, before starting with the interview stage, a pilot phase was conducted to test and adapt the interview guideline. Finally, to allow for a computer-assisted empirical analysis of the collected interview data, the interviews were recorded and later transcribed by a professional transcription service provider who was not part of the research team.

3.2 Qualitative content analysis

We use qualitative content analysis (QCA; Mayring 2000; Kuckartz 2014) to empirically identify the multidimensional relationship between digitalization and firm-level innovation according to various main and sub-categories. For this purpose, we apply and combine both deductive and inductive reasoning to obtain an overall picture of the various facets of the digitalization-innovation link in SMEs. MAXQDA was used throughout the qualitative data analysis. The methodological approach and the respective steps are shown in Figure 2. On the right side of Figure 2, an additional column is added indicating in which sections of the present paper the results of each step can be found.

Figure 2. Steps of the qualitative content analysis (QCA)



Notes: Own compilation based on Mayring (2000); Kuckartz (2014).

Starting from our research question, the first step of the QCA is a review of the OM 2018 on the potential links between digitalization and firm-level innovation. On this basis, a deductive formulation of different thematic categories is conducted. For this purpose, we reformulated the identified aspects from the OM 2018 review shown in Table A1 (Appendix) as main and sub-categories through which a first structuring of the interview data in terms of content could be achieved (Steps 2 and 3). The transcripts were read through from this perspective, striking passages were marked and memos were written. Most importantly, all of the interview material was coded along the deductive OM 2018 categories. In steps 4 to 6, all text passages coded in the interview transcripts with the same category were compiled and reviewed. This served to allow a further differentiation of the categories after finishing the first part of the coding process. Memos and the markings of important text passages were used at this point for a continuous reconsideration of chosen codifications and to create a solid basis for the later interpretation of the category system. Moreover, based on the interview material we inductively derived further main and sub-categories with relevance to the digitalization-innovation link in SMEs that extend beyond the OM 2018. If necessary, the categories deductively derived from the OM 2018 were adapted and modified in light of the evidence from the interview data. As a result, the QCA led to an advanced category system in which all of the interview material was coded one further time to achieve a finer content structuring of the interview material.

Since further categories or the need to revise existing ones could arise at any time during the coding process, steps 4 to 6 were conducted several times, which implies that the interview data has been analysed on a recurring basis (dashed line on the left side of Figure 2). Through the entire coding procedure, the material was always first completely coded by the same member of our research team to avoid potential problems due to insufficient intercoder reliability.

Only in a second step did another researcher check the coding in each case so that potential disagreements in terms of coding preferences could be discussed and solved. At this point, special care was taken regarding the straightforward interpretation of text passages and their allocation to certain categories. Finally, Step 7 of the QCA refers to the presentation and discussion of the final empirical results. This includes a category-based interpretation of the final category system and an analysis of the interrelationships between different sub-categories.

4. Empirical results I: Review of the OM 2018

Table A1 in the appendix summarizes the various digitalization aspects discussed in five chapters of the OM 2018 from an innovation measurement perspective. The first one (Chapter 3) is about the definition of various types of innovation outcomes by considering the digital transformation. The relevance of digitized information is shown from the perspectives of product and business process innovation activity. In the case of defining product innovation, this means that the renewal or improvement of goods in terms of integrated software or the degree of their digital nature as well as the digitalization of services are explicitly addressed in the revised manual. The definition of business process innovation now also covers the adoption and modification of digital technologies within firms "to codify processes and procedures, add functions to existing processes and enable the sale of processes and services" (OECD/Eurostat, 2018, p. 72-73). Digital-based business process innovations are therefore to be found along the full range of business functions, such as production, service delivery or marketing. Business model innovations in response to the digital transformation are defined in the OM 2018 as typically involving either the digitalization of a firm's products or business processes, or both (for example, in the course of switching to digital business processes to sell or deliver products).

Chapter 4 of the OM 2018 discusses the role of software development and database activities. The manual lists these two – along with seven other areas (including R&D, employee training, marketing, etc.) – as innovation activities if they contribute to product, business process or business model innovation. While digitalization can potentially play a role in different types of innovation activities, it holds central importance in firms that take steps in data development activities (including software) in their pursuit of innovation. Software development constitutes an innovation activity, for example, when software is integrated in existing products or services to renew or improve them. Digital database information holds relevance when its use results in product or business process innovations.

Furthermore, in line with the our theoretical framework of the digitalization-innovation link in SMEs (Section 2), the OM 2018 emphasizes "the enabling, general purpose nature of digital technologies and data analytics" (OECD/Eurostat, 2018, p. 118). Thus, digital competences are described in Chapter 5 as a key business capability with high relevance for innovation activities. This includes the use of digital technologies, the existence of in-house capabilities required for it and the availability of data management competences, whereas in each case the digital skills of the workforce are deemed to be highly important (see Table A1).

The OM measurement guidelines also account for the fact that the digital transformation affects the way in which firms and other actors in the innovation system are interacting and learning with each other. Thus, the role of digital-based knowledge flows in innovation activities and their potential effects for a firm's cooperative and competitive environment are described in the OM 2018's Chapter 6 as another dimension of the digitalization-innovation link (Table A1). Finally, Chapter 7 of the OM 2018 discusses the measurement of external market factors driving digital-based innovation. Such drivers described in the OM 2018 are the digital nature of a firm's market, the influence of customers and users on the incentive to engage in digital-based innovation, the role of suppliers as a source of digital technologies/competences and the relevance of online sources through which firms can find new ideas and information for innovation. Throughout this discussion, the role of digital platforms is assigned strong importance, reflecting not least their high innovation potential for SME (Kenney et al., 2019; Ben Arfi and Hikkerova, 2021).

5. Empirical results II: Interview data

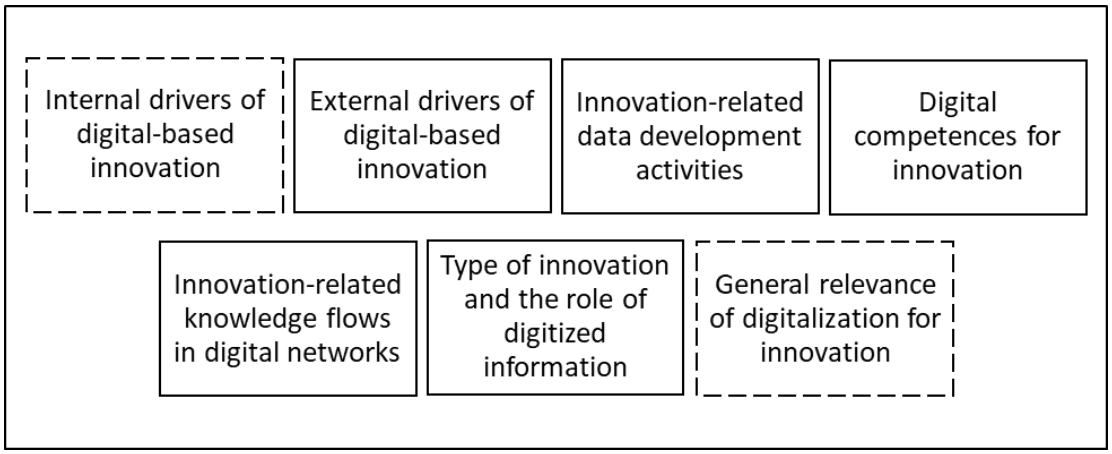
5.1 Main categories of the digitalization-innovation link in SMEs

Five of the main categories derived fully or partly relate to the OM 2018 (see Figure 3), two of which belong to Dimension 1 of our theoretical framework presented in Section 2 ("External drivers of digital-based innovation", "Innovation-related knowledge flows in digital networks"). Two of these main categories belong to Dimension 2 ("Digital competences for innovation", "Innovation-related data development activities") and one to Dimension 3 ("Type of innovation and the role of digitized information").

On this basis, we developed a first set of deductive categories. However, while coding the interview material along these five main categories, we encountered several relevant text passages for the digitalization-innovation link that

could not be assigned to any of them. Thus, detached from the OM 2018, we inductively developed two additional main categories under which the corresponding text passages could be summarized and coded. As a result, our final category system comprises seven main categories (see Figure 3). First, the "Internal drivers of digital-based innovation" category covers a number of within-firm organizational determinants of the digitalization-innovation link and thus relates to Dimension 1 of our theoretical framework (see Section 2). Second, the "General relevance for innovation" category comprises several passages of the interviews describing how SME representatives reflect the perceived overall impact of the digital transformation on their business and innovation model. Correspondingly coded interview material thus lies somewhere between Dimension 1 and 2 of our theoretical framework of the digitalization-innovation link in SMEs.

Figure 3. Deductive and inductive development of the main categories



Notes: Main categories with solid lines are fully or partly derived from the OM 2018; while main categories with dashed lines are only derived from the interview data.

Finally, in case of the "External drivers of digital-based innovation" category, we started with Chapter 7 of the OM 2018 (which deals with external market factors that drive digital-based innovation) to derive our deductive categories. However, the interview material indicates that other, non-market impulses from the external environment also play a role for a firm's decision to engage in digital-based innovation activities. As such – in extending the OM 2018 – for example, collaborations with universities or the role of informal networks are also covered by this main category.

5.2. Description of the subcategories

For each of the seven main categories, we developed a set of sub-categories in accordance to the procedure described above (see Figure 2). Table A4 in the appendix presents the final category system in detail, including the labels of the main and sub-categories and the definitions of the categories used for guiding the coding process. In each case, exemplary quotes taken from the interview material are given for illustration. Moreover, the total number of coded segments within the interview transcripts are added for each sub-category.

The main category of "Internal drivers of digital-based innovation" is divided into four sub-categories. A number of SME respondents reflected on the (potential) benefits of digital-based innovation activities in terms of *automation and increased efficiency* (e.g. I5, I7, I20, I42). It several cases, the pursuit of automation and efficiency benefits to optimize internal business processes was the firm's starting point for engaging in digitalization (e.g. I16, I49). Members of more digitalized companies tended to emphasize the importance of a *business culture* that is conducive to learning and digital-based innovation (e.g. I1, I5, I7, I20). Interviewees from both less and more digitalized companies frequently mentioned the role of *employees*. It emerges that employees are generally important for the within-firm implementation of the digitalization-innovation link. Especially younger employees are reported to trigger digitalization at the company level (e.g. I22, I26, I32). Regarding the input side of digital-based innovation, a number of interviewees also emphasized the gatekeeping role of the *business owner/entrepreneur* in bringing in new ideas about the innovation potential of digitalization and convincing sceptical employees to adapt to corresponding digital technologies and practices (e.g. I5, I9, I26, I32, I39). However, it also emerges that the business owner can also constitute a barrier to successful digitalization processes due to ignorance and refusal of the need to use digital technologies (e.g. I43).

Regarding the main category of "External drivers of digitalization", our interview data confirms that *customers* play a multifaceted role for the digitalization-innovation link. They can clearly drive digital-based innovation efforts. A number of SMEs report that they integrated digital technologies in their products or services to create an innovative benefit from their customers' perspective (e.g. product improvements through the integration of software applications – I8). In terms of process innovation, the QCA's results show that digital technologies have opened up new possibilities for SMEs to interact with their customers (e.g. through data collected via sensors in new products – I32). The exchange with *suppliers* is another external precondition for digital-based innovation, in particular when larger-sized suppliers push smaller firms to adapt to new digital standards and integrate them into their digital supply chains (I17).

Furthermore, several SME interviewees report that they monitor their *competitors* to ascertain which digital technologies and practices have proven useful under similar market conditions, which then often provides the impetus for digital-based innovations that are new to the firm. On the other hand, SMEs that have adopted a digital-based business model often did so to gain a competitive advantage over their rivals (e.g. by creating a digital sales channel as a distinguishing feature – I12) or because they were literally forced to do so by competitors with a digital business model.

In terms of cooperation activities, digital technologies are reported relatively often to be either means or purposes of formal and informal *firm networks* in which some of our SME interviewees are engaged, with firms from either the same industry or other sectors. *Trade fairs and trade magazines* are another external driver of digital-based innovation activities in SMEs. A number of SME interviewees report visiting trade fairs (or reading trade magazines) to obtain knowledge inputs about new digital technologies and their potential applications in practice. Several interviewees also consider *digital platforms, websites and databases* as valuable sources for finding new ideas to improve their products and processes.

Besides these market factors, other external factors also prove important for the digitalization-innovation link. The SME interviewees relatively frequently use their contacts with *universities and institutes* to recruit young employees with advanced digital skills. However, apart from such recruitment purposes, research projects on digitalization in cooperation with universities or other external research institutes are often seen critically by the SME representatives, because such efforts are perceived to be too time-consuming, bureaucratic and not sufficiently productive in terms of economic benefit. A further external non-market factor that drives digital-based innovation activities is *regulations and norms*. Our SME interviewees report that this factor can be a barrier as well as a driver of digitalization (for example, in case of the EU General Data Protection Regulation – I22, I34). Finally, it has been shown that public *funding* can be a further external driver for the digitalization-innovation link in SMEs.

Regarding the main category "Innovation-related data development activities", the QCA's results confirm that *database activities* are an integral part of innovation activities in SMEs (e.g. when databases are used to avoid the potential loss of critical innovation-related knowledge – I39, I40, I45, open up new opportunities for interactive learning within the company – I34, or serve as a basis for continuous improvement of products and processes – I49). Several firms in our interview sample also refer to the *development of software* in the context of their innovation activity, which shows how important software has now become for the creation of new or improved products, services or processes for various SMEs.

Several sub-categories have been identified in the main dimension of "Digital competences for innovation". Competences in *data protection* is the first in this regard. Our interview data shows that conducting digital-based innovation activities requires adequate management of privacy and cybersecurity risks (e.g. I18, I33). For obvious reasons, *training activities* are another content category in the digitalization-innovation context. On the one hand, this concerns the digital support of innovation-related training programmes (e.g. I49). On the other hand, it is more common that this sub-category refers to the ongoing need in innovating SMEs to keep employees up to date on new digital technologies and practices in the workplace (e.g. I26, I30, I43, I47). The interview material further shows that competences for creating and sustaining *digital internal connections* are essential for the conduct of business process innovation; for example, by organizing within-firm communication flows more efficiently through the use of digital tools. Such a digital integration within and across different business functions can facilitate the collection and exchange of new innovation-related ideas between people and departments of a company (e.g. I49). Besides digital internal connections, a firm's competences in *digital external connections* also often form a basis for innovation. Several SME interviewees report that they now communicate mainly digitally with their suppliers and customers. For example, some firms have integrated suppliers into their digital organizational system (I49) or use digital external connections to their customers for after-sales service or web marketing (I17, I19, I38).

Another area of digital competences relates to *knowledge management*. A number of firms in our sample emphasize the importance of experiential knowledge for innovation, which needs time to accumulate and is often held by older employees or employees in key positions. In order to secure this knowledge for the company in the longer term and be

less dependent on specific employees, the digital storage of such know-how is perceived as crucial for firm innovativeness by several respondents (e.g. I15, I16, I35, I37, I49). *Data analytics for innovation* is another part of an SME's digital competence portfolio. The use of data analytic tools in firms can be important for introducing product novelties or driving business process innovation. For example, an SME from the service sector (I17) offers improved building automation to its customers by not only collecting user data via a digital instrumentation and control system but also in being able to analyse this data to offer comprehensive remote maintenance functions.

Unsurprisingly, digital competences at the company level are closely linked to the *use of digital technologies*. The corresponding sub-category is specifically about the use of new digital tools and methods in innovating SMEs. Hence, we included all text passages that mention electronic tools, systems, devices or other digital technologies to "generate, store, process, exchange or use digital data" (OECD/Eurostat 2018, p. 121). While some firms employ basic digital ICT to benefit from automation, other firms use more advanced digital technologies to connect and integrate various business activities and functions or to tailor products and services to customer needs (e.g. I16, I18, I36, I39, I40). Finally, the sub-category of *digital capabilities and skills* reflects on the in-house capabilities for digitalization. For example, some SME interviewees have their own IT department, an own mission statement with guiding values on the company's digital transformation, a separate budget for costs in electronic data processing or emphasize the digital qualifications of certain people in the firm (e.g. I1, I21, I23, I32, I47).

The first sub-category of the main dimension "Innovation-related knowledge flows in digital networks" refers to the fact that several SME interviewees use digital technologies for external *interactions and exchanges* to ensure efficient knowledge flows. Our interview material reveals that firms can face different challenges when exchanging innovation-related knowledge with external actors via digital channels (e.g. in terms of complying with security standards – I34, or managing the risk of information or knowledge loss when using digital technologies in collaboration activities (e.g. I4, I14, I23, I34, I49). It is therefore unsurprising that some respondents also reflect on the role of *trust* in external digital networks. For example, SMEs interviewees state that while it is perfectly fine to communicate with customers or other external partners through digital channels, it remains best in case of critical questions to meet face-to-face to solve innovation-related problems (I21, I26, I35). In addition, there are questions of appropriability arising in terms of *diffusion and exclusion*. Especially for SME interviewees from the ICT sector, open source constitutes an important element of software development. Therefore, for example, most software firms in our data are opposed to software patents (e.g. I4, I23).

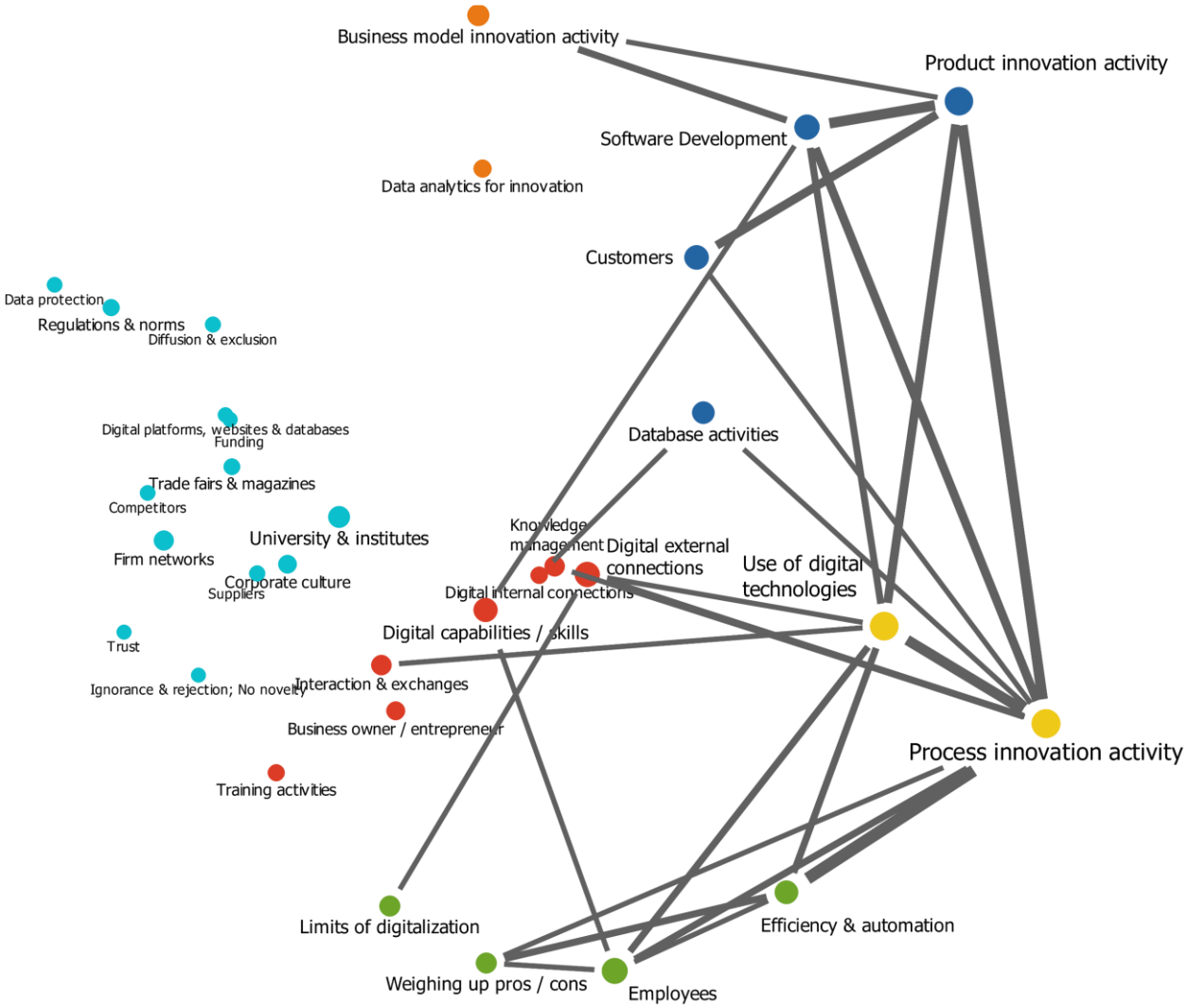
The sixth main category – labelled "Type of innovation and the role of digitized information" – has already been touched on couple of times in the above discussion. The description of the other sub-categories confirms that digitalization can either be a competence factor that drives innovation in SMEs, or it can itself constitute an innovation outcome. In this regard, we make no distinction whether the digital-based innovation activity has taken place in the past, is recently completed, currently not yet completed or being considered potentially for the future by the SME respondents. The sub-category of *process innovation activity* refers to the use of digital technologies during the implementation of new or significantly improved business processes (e.g. I18, I25, I47). On the other hand, digitalization is linked to *product innovation activity* when digitized information forms a distinct part of new or significantly improved products or services. For example, a number of manufacturing SMEs in our sample report that their recent product improvements are based on the implementation of software applications or sensors (e.g. I8, I31, I49). Digitalization activities can also result in *business model innovation*. Text passages with codes on this sub-category refer to an SME's experiences with digital business models, e.g. by implementing the digital transformation of the company's products or business functions in an all-encompassing sense (I17, I18, I22, I23, I32) or switching to a business model for digital market environments (I6, I11, I33, I47, I49).

Finally, the interviewees also reflected about the "General relevance of digitalization for innovation". The corresponding results show a number of reasons why innovating SMEs may still refrain from more intense digitalization activities or why they do not attribute them much relevance in terms of innovation. For example, some companies tend to ignore or even reject the current digitalization trend (*ignorance & rejection; no novelty*), because they see no need to use new digital technologies as they assume that their business model will work successfully without further digital transformation. Some say that digitalization, in a sense, is past history for them and therefore not innovative from their perspective (e.g. I19, I25, I38). A larger number of respondents refers to *limits to digitalization* that occur because either certain business processes still require human interaction or certain people-related barriers within or external to the firm are hindering the implementation of more advanced digital technologies and practices (e.g. I8, I19, I20, I27, I45, I47). Finally, several SME respondents report that they are *weighing up the economic pros and cons* before taking further digitalization steps. This reflects the typical resource constraints of smaller companies, which means that many SMEs tend to prefer to rely on established standards due to risk considerations rather than trying out new but hitherto hardly tested digital technologies (e.g. I3, I7, I21, I29, I47).

5.3 Interrelationships between the sub-categories

To further delve into the various connections between individual sub-categories, a code map has been created to visualize how closely different categories are related to each other in terms of content from the SME respondents' perspective (Figure 4). In the code map, each category is symbolized by a circle, with the distances between two categories reflecting how similar the corresponding topics have been mentioned by an SME interviewee (measured by the proximity of codes in each interview document). The more codings to which a category has been assigned in the data, the larger its circle will be. Moreover, colours are used to highlight the affiliation to six groups of categories. The grouping and colouring of the categories are undertaken by MAXQDA based on a hierarchical cluster analysis (unweighted average linkage) of the positions on the code map. In the case of overlapping codes at a text segment, the connecting lines between two categories are shown when there are at least 25 times intersections in the interview data, since this allows highlighting the most relevant associations between the codes of those text passages that are more distant from each other in an interview document. The more interrelationships that have been measured in this way, the thicker the connecting lines are displayed.

Figure 4. Code map – sub-categories positioned according to their similarity within the same interview document



In line with the theoretical framework presented in Section 2, the code mapping results show the complex interplay between digital technologies, competences and innovation in SMEs. Digital competences and related knowledge-based activities such as database activities or software development (i.e. Dimension 2 of our theoretical framework) are central when it comes to the link between digitalization and SME innovation (mainly red circles, partly also blue and

orange). For obvious reasons, this is especially true for the use of digital technologies as the "spider in the web" with which everything is connected, both in terms of competence factors that drive innovation and as a specific component of different types of innovation outcomes. It is interesting that the business owner is to be found in the area of innovation-related digital competences, which may point to his or her gatekeeping function in the context of SME innovation (on this issue, see Runst and Thomä, 2022).

To the left of the digital competences categories are various internal and external drivers of digital-based innovation (light blue dots), which often provide the first impetus for building up digital competences (i.e. Dimension 1 of the theoretical framework). Furthermore, the code map confirms the fact that the use of new digital technologies is closely related to process innovation activity in SMEs at the output side (yellow circles; Dimension 3). This shows that digitalization in innovating SMEs is strongly associated with new or improved business processes. In this respect, employees are closely involved as both drivers and possible inhibitors (green circles). The efficiency motive also fits into this connection between the employee level and process innovation activity. This suggests that digital-based process innovation is primarily aimed at improving efficiency of the company's operations through an automation of tasks that humans used to do. The interview data shows that in this context SMEs face the ongoing challenge of weighing up the economic pros and cons of further digitalization steps and testing the associated limits.

Relatively unrelated to this nexus of input drivers, digital competences, automation benefits and process innovation activity is the conduct of digital-based production innovation (dark blue circles; Dimension 3) and – closely related to this – of digital business model innovation (orange; Dimension 3), suggesting that some of the SMEs in our interview sample have already reached a more advanced level of digitalization maturity. As expected, software development and product innovation activities are closely interlinked, which confirms that the integration of software elements has become a key feature of new or improved products and services (Figure 4). Moreover, customers often are strongly involved in such digital-oriented product innovation activities. This probably also explains the closer relationship with database activities, as digitally stored information on customers is becoming increasingly important for analysing customer preferences during the innovation process (OECD/Eurostat, 2018). The same applies with regard to the proximity to competences in innovation-related data analytics, which are an important prerequisite for the successful adoption of digital-based business models (orange).

5.4 A basic test of validity

The observed interrelationships between the sub-categories already indicate that there is a dichotomy between digital-based process innovation on the one hand and digitally driven product/business model innovation on the other, reflecting the conceptual distinction discussed in Section 2 between digital-based innovation outcomes based on the principle of "doing the same with less" and those based on the principle of "doing something new". To illustrate the category system's potential for innovation measurement, we therefore conducted a basic test of validity. To this end, we leave the within-document level of analysis and switch to an across-company perspective so that different groups of the 49 innovating SMEs in our sample can be compared with each other based on a set of explanatory variables. For this purpose, the innovating SMEs in our sample are clustered according to their digital competences (eight sub-categories) and related knowledge-based activities (i.e. the sub-categories database activities and software development) by using the MAXQDA's Document Map Tool. We have chosen these cluster variables because both theoretically (Section 2) and against the background of the empirical results above, it can be assumed that the digital competence portfolio of an SME (i.e. Dimension 2 of our theoretical framework) is likely to be a main driver of variability between firms in terms of the digitalization-innovation link.

The assessment of similarity between individual companies is based on the basic occurrence of codes in the companies' interview transcripts, as the absolute frequency of codes could be biased by the specifics of each interview situation and does not necessarily tell us something about the similarity of two companies. For the same reason, we use the Jaccard algorithm as a similarity measure. This only considers the co-occurrence of codes in different documents as similarity and neglects a joint non-occurrence of codes.

According to the document map's results, a three-cluster solution fits the data quite well (Table 1).[2] The first cluster consists mainly of companies with only a few codes for the subcategories considered, indicating that the members of this group have relatively weak digital competences. A closer look at the cluster results (Table 1) shows that the percentage of companies with digital competences and related knowledge-based activities is only below average in the

[2] The visual grouping of the surveyed SMEs according to their digital competences (document map) is available from the authors upon request.

case of the first cluster, with the exception of digital external connections. This indicates that the respective companies have so far only taken first steps in digitalizing their innovation processes by using basic digital communication technologies to improve their interactions with external partners such as customers and suppliers. This interpretation is consistent with the results in Table A5 in the appendix, where the other subcategories that were not used for clustering are employed to create descriptive cluster profiles. Accordingly, on both the input and output side of digital-based innovation (i.e. Dimension 1 and 3 of the theoretical framework), members of the first cluster are less likely to be represented in the respective subcategories. Against this background, we refer to this first group of SME innovators as "Beginners in digital-based innovation".

The second cluster of innovating SMEs includes companies that have already built up some competence portfolio in terms of digital-based innovation (see Table 1). According to the cluster results, they are above average in terms of database activities, training, digital internal connections, knowledge management and the use of new digital technologies, indicating a strong focus in the area of digital improvement of internal business processes (i.e. Dimension 2 and 3 of the theoretical framework). The cluster profiles with regard to the other subcategories confirm this. The efficiency & automation motive and the associated weighing of economic advantages and disadvantages of further digitalization is relatively likely for the second group, often stimulated by visits to trade fairs, reading the trade press and suggestions from suppliers (which relates to Dimension 1). At the same time, the likelihood of digital-based product or business model innovation is rather low in this group (see Table A5), which is why we name the second cluster as “Digital-oriented process innovators”.

Table 1. Clustering of innovating SMEs according to their digital competences

	Sample mean	**Cluster 1 (N=9)**	**Cluster 2 (N=16)**	**Cluster 3 (N=24)**
Database activities, number of firms (%)	24 (49.0)	1 (11.1)	**9 (56.3)**	**14 (58.3)**
Software development, number of firms (%)	24 (49.0)	1 (11.1)	0 (0.0)	**23 (95.8)**
Data protection, number of firms (%)	10 (20.4)	2 (22.2)	0 (0.0)	**8 (33.3)**
Training activities, number of firms (%)	17 (34.7)	1 (11.1)	**10 (62.5)**	6 (25.0)
Digital internal connections, number of firms (%)	17 (34.7)	2 (22.2)	**7 (43.8)**	8 (33.3)
Digital external connections, number of firms (%)	34 (69.4)	**9 (100.0)**	7 (43.8)	18 (75.0)
Knowledge management, number of firms (%)	24 (49.0)	0 (0.0)	**10 (62.5)**	**14 (58.3)**
Data analytics for innovation, number of firms (%)	13 (26.5)	0 (0.0)	4 (25.0)	**9 (37.5)**
Use of digital technologies, number of firms (%)	35 (71.4)	5 (55.6)	**15 (93.8)**	15 (62.5)
Digital capabilities / skills, number of firms (%)	30 (61.2)	0 (0.0)	11 (68.8)	**19 (79.2)**
N = number of firms (Share of sample in percent)	49 (100.0)	9 (18.4%)	16 (32.7%)	24 (49.0%)
Cluster label		Beginners in digital-based innovation	Digital-oriented process innovators	Digital product/business model innovators

Notes: Percentages that are relatively high above the sample mean are marked in bold.

The third and largest cluster contains the companies with the most developed digital competences in our sample. Compared to the other two clusters, SMEs in this group put a relatively high emphasis on database activities, software development, data protection, knowledge management, data analytics and digital capabilities / skills (see Table 1). The cluster profiles confirm that the companies in this group have a strong commitment to combine digital technologies and corresponding competences with their innovation activity (i.e. they are integrating all three dimensions of the theoretical framework), which is why the question of the pros and cons of digitalization hardly arises anymore (Table A5). This is illustrated by the fact that they are likely to maintain a distinct culture of information and knowledge sharing, experimentation and informal exchange in the context of their digital-based innovation activities (business culture) and that these firms attribute high importance to the role of employees and owners for the successful within-firm implementation of the digitalization-innovation link.

In addition, their external market environment and their involvement in external knowledge flows, networks and interactions with external partners are strongly shaped by the digitalization, which is why it can be assumed that their business model is fully or largely aligned with the requirements of digital innovation. This is exactly what the cluster profiles show with regard to the output side of innovation: The introduction of digital-based product or business model innovations is comparatively very likely in case of the third group (see Table A5). Therefore, we choose "Digital product/business model innovators" as the cluster label for the third group of SMEs. Overall, we interpret these clustering results as an indication that the category system developed in this paper has predictive validity.

6. Discussion and conclusion

Digitalization is one of the main trends that affects innovation today. In this context, there remains considerable room to improve our understanding of the complex interplay between digital technologies, competences and firm-level innovation. Against this background, the present paper empirically examines the role of digitalization in the context of SME innovation to provide a basis for better measuring the digitalization-innovation link at the company level. This is theoretically rooted in a three-dimensional understanding of the digital transformation of innovating SMEs: as an innovation-promoting input factor, as a competence factor shaping the innovation process and as an output of a firm's innovation activity in itself.

Using the fourth edition of the Oslo Manual as a starting point for a qualitative content analysis (QCA) of interview data on innovating SMEs, a category system is derived that covers the multidimensional relationship between digital technologies, competences and SME innovation along seven main categories and 32 sub-categories. The potential of this category system from an innovation measurement perspective was tested by using it to identify, in an exploratory manner, different groups of innovating SMEs with regard to digital transformation. The corresponding results confirm that there are three groups of "digitalizers" among innovating SME. First, beginners in digital-based innovation that use basic digital technologies for communication with external partners such as customers or suppliers. Second, digital-oriented process innovators who are using new digital technologies and practices to achieve efficiency and automation benefits by improving their internal business processes. Third, digital product/business model innovators that are strongly investing in the digitalization of their products and services and often already have extensive experience regarding the adoption of digital-based business models. In light of these results, we conclude that the derived category system has predictive validity – demonstrating its relevance for future revisions of the Oslo Manual.

Hence, there is a great variety of SMEs in terms of the possible links between digitalization and innovation. While some SMEs are slow to find their way into digitalizing their innovation processes, others have started to use new digital technologies for efficiency reasons in the sense of "doing the same with less", while still others are aligning their entire business model with the requirements of digital environments based on the innovation principle of "doing something new". This also indicates the potential that the derived category system offers from the perspective of managers and innovation policy. Our results illustrate how strongly the innovation activities of SMEs are already shaped by the digital transformation, and, at the same time, they show at which different points at the company level the digitalization-innovation link can be influenced.

However, there are also certain limitations associated with this paper. Of course, the potential weaknesses of qualitative research apply. For example, even though this was not the objective of our study, it remains unclear how strong the relative weight of the three different groups is in the overall population of innovating SMEs. Something similar applies regarding the interpretation of causal relationships between the different dimensions of the digitalization-innovation link in SMEs. Several of our arguments regarding the multidimensional relationship between digital technologies, competences and innovation should therefore be interpreted with caution regarding causal inference. This also points the way for future research efforts. A promising approach would be to bridge the gap to quantitative innovation measurement by developing concrete indicators for the individual main and sub-categories and systematically evaluating them based on quantitative innovation surveys. This is already happening to some extent. For example, starting with the survey year 2019, the new guidelines of the OM 2018 for defining product and business process innovations by taking into account digital aspects have been implemented in the German CIS (Mannheim Innovation Panel). However, to better understand the multidimensional relationship between digitalization and firm-level innovation highlighted in this paper and, for example, to verify our findings, further efforts in this direction are needed.

Appendix A

Table A1. The Oslo Manual 2018 on digitalization and its potential links with firm-level innovation

OM 2018	Main topic	Content
Chapter 3	The link between digitalization and different types of innovation	- Defining product innovation regarding digitized information (including pure digital products and supporting business processes that require ICT or web/software development) - Defining business process innovation with respect to the firm-level adoption and modification of digital technologies - Discussing digital-based business model innovation and their relationship with product and business process innovations
Chapter 4	Data development activities along with software as a potential innovation activity	- Software development and database activities are given as an example for innovation activities at the company level - Software development is an innovation activity when used to develop new or improved business processes or products - Database activities are an innovation activity when analyses of data on the properties of materials or customer preferences are used for innovation
Chapter 5	Digital competences for innovation	- Digital competences are defined as a distinct part of the wider technological capabilities of a firm (due to the general purpose nature of digital technologies and data analytics) - Three components of innovation-related digital competences are to be distinguished: (1) a firm's use of different digital technologies (e.g. advanced digital tools and methods; digital platforms) (2) a firm's in-house capabilities for using digital technologies (IT resources, digital skills, digital strategy/vision) (3) a firm's data management competences, including the acquisition of external data analytics services (e.g. database management systems, data mining tools, machine learning, user behavior analysis or real time data analysis)
Chapter 6	Digital-based knowledge flows with relevance to innovation	- Knowledge flows and exchanges between firms and other actors in the innovation system nowadays often are strongly supported or facilitated by digital information and communications technology (ICT) - This affects both a firm's cooperative and competitive interactions with other firms or institutions (e.g. decentralized collaboration models supported by digitalized knowledge)
Chapter 7	External market factors as drivers of digital-based innovation	- External market factors can have a major impact on a firm's incentives for digital-based innovation activities - Major drivers of how a firm's external market environment can influence innovation in terms of digitalization are: (1) The nature of a firm's markets (notably with respect to the role of digital platforms, the existence of main competitors with digital business models or in terms of geographical coverage and the role of digital marketing) (2) The influence of customers and users (is there a demand for digital-based innovation?) (3) Suppliers as an important source of digital technologies/competences (4) Online sources to find ideas and information for innovation (the use of external business websites, searchable repositories or databases in the pursuit of innovation)

Source: OECD/Eurostat (2018)

Table A2. Detailed information on the SME interviews

No. of interview	Industry	Position of interviewee	Region	Number of employees	Duration of interview (minutes)
1	Professional, scientific and technical activities	CEO	Goettingen	12	104
2	Mining and quarrying	CEO	Goettingen	3	66
3	Construction	Executive	Goettingen	10	73
4	Information and communication	CEO	Goettingen	61	96
5	Manufacturing	CEO	Goettingen	16	73
6	Wholesale and retail trade; repair of motor vehicles and motorcycles	CEO	Goettingen	20	67
7	Manufacturing	Executive	Goettingen	143	64
8	Manufacturing	CEO	Goettingen	50	71
9	Information and communication	CEO	Goettingen	1	76
10	Transporting and storage	CEO	Goettingen	3	63
11	Manufacturing	Executive	Goettingen	91	40
12	Manufacturing	CEO	Goettingen	100	64
13	Wholesale and retail trade; repair of motor vehicles and motorcycles	CEO	Goettingen	1	78
14	Professional, scientific and technical activities	CEO	Goettingen	7	69
15	Manufacturing	CEO	Goettingen	33	80
16	Manufacturing	CEO	Goettingen	24	84
17	Professional, scientific and technical activities	CEO	Goettingen	12	58
18	Manufacturing	Development	Goettingen	103	75
19	Other services activities	CEO	Hanover	4	60
20	Construction	CEO	Hanover	120	70
21	Professional, scientific and technical activities	CEO	Hanover	4	64
22	Information and communication	CEO	Hanover	35	55
23	Information and communication	CEO	Hanover	5	70
24	Human health and social work activities	CEO	Hanover	30	33
25	Manufacturing	CEO	Hanover	46	85
26	Manufacturing	CEO	Hanover	26	64
27	Manufacturing	CEO	Hanover	12	44
28	Manufacturing	CEO	Hanover	15	90
29	Agriculture, forestry and fishing	CEO	Hanover	104	40
30	Manufacturing	CEO	Hanover	17	87
31	Manufacturing	CEO	Hanover	170	42
32	Information and communication	CEO	Hanover	7	66
33	Wholesale and retail trade; repair of motor vehicles and motorcycles	CEO	Hanover	14	74

Table A2. (continued)

34	Manufacturing	CEO	Jena	70	92
35	Manufacturing	CEO	Jena	170	150
38	Manufacturing	CEO	Jena	23	29
39	Manufacturing	CEO	Jena	97	39
40	Manufacturing	CEO	Jena	58	35
41	Manufacturing	CEO	Jena	50	17
42	Manufacturing	CEO	Jena	200	89
43	Wholesale and retail trade; repair of motor vehicles and motorcycles	CEO	Jena	5	26
44	Manufacturing	CEO	Jena	25	49
45	Manufacturing	CEO	Jena	33	32
46	Information and communication	CEO	Jena	10	12
47	Manufacturing	Executive	Jena	140	70
48	Manufacturing	CEO	Jena	25	89
49	Manufacturing	Executive	Jena	150	109
			Mean	**49,7**	**64,9**

Table A3. Interview guide

Category	**Questions**
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 introduced 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?; If yes, 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, in particular 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 modifications 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?; If yes, 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?

Source: Alhusen et al. (2021)

Table A4. Detailed category system including definitions and exemplary quotes

Main category	Sub-categories	Definition	Exemplary quotes (no. of interview in brackets)	Coded segments
Internal drivers of digital-based innovation	Efficiency & automation	Basic digital technologies are employed to exploit benefits of automation and increased efficiency	"Autonomous Industry 4.0 means – we have just made our first experiences with co-bots – that we are simply experimenting and getting a few things started. We also have automated machines and we have robots in use. We don't consider this to be Industry 4.0, but rather we simply want to use automation." (I47)	62
	Corporate culture	A culture of information and knowledge sharing, experimentation and informal exchange facilitates digital-oriented innovation activities	"R&D is second nature to us. We could do a workshop every day, every weekend, and build a new sensor. So now this weekend it's happening again, because I was at the trade fair yesterday and said I have an idea, we have to try something out. And now we're going to sit down this weekend, spend a whole Saturday together and solder a new sensor. Then I have a certain product idea and we'll just try it out." (I32)	34
	Employees	Employees are essential for the successful within-firm implementation of the digitalization-innovation link	"So, the CNC machining, of course, we have different types of software at our company to program machines. [...] We have found that the younger employees cope much better with the new software than older ones. I don't even know how many we've tested. The newer employees are much more comfortable with this type of programming task, probably also because of the training they have received. [...] Older employees have great problems using the software, as they don't grasp the complex interrelationships like younger people do." (I26)	75
	Business owner / entrepreneur	Owners/entrepreneurs are a main driving force of digitalization in terms of bringing in new ideas and perspectives	"My father was actually always one who always looked ahead, always going further and further. He always wanted to grow, it wasn't that he was reluctant. But where he always resisted was an online store. For example, this he didn't want to do at all, which, in turn, has been on my mind ever since I took over the company, thinking about how I want to implement it, which, as I said, I've already started to do." (I43)	35
External drivers of digital-based innovation	Regulations & norms	Regulations and norms can be a barrier as well as a driver of digitalization	"Or now, for example, the GDPR *[General Data Protection Regulation]*, a great thing. So, I'm totally happy about that topic, because of all the compliance constraints you can impose on the customer and say: Watch out, you have to comply with data protection. Don't mess around. That's positive, so the customer is closely guided and there's nothing better, legal constraints are the best thing ever." (I4)	25
	Public funding	Public funding can support innovation-related digitalization activities at the company level	"To drive digitalization here, in order to optimize business processes, reduce errors, save money and things like that, we also have an innovation program from the NBank *[i.e. the development bank for the German federal state of Lower Saxony]*, to which we applied for funding, which was later approved, and we are just initiating digital processes here at a high speed, it's fantastic!" (I25)	15

Table A4. (continued)

	Universities & institutes	Enhancement of digital skills through recruitment of university graduates and cooperation with universities and other external research institutes	"But instead we have people, who come from the university, who can then operate with advanced tools due of their training. One of the most important ones was someone who came from the FHDW. That is the university of applied sciences that we have here in Hanover, which offers dual training. [...] And then we had a working student for half a year, who was well versed in information technology, he really boosted us here. [...] So he helped us a lot with our digital processes." (I25)	52
	Firm networks	Formal and informal exchange with firms from the same industry and firms from other sectors	"As we are a rather small team, everyone brings something in at some point. When university graduates join us, it's often the employees through whom they who come to us, or you hear from them from friendly companies. If these firms use a new software and say it's particularly great, than we would also try something like that, but we don't have a formalized process in this regard." (I17)	42
	Trade fairs & trade press	Knowledge inputs for digital-based innovation activities through trade fairs and trade magazines	"But the real reason, or a very big reason, to go to a trade fair is, of course, to look around: What's there? [...] What didn't interest me at all in the past, because it was unimportant to me, is actually the most important thing for me today: observing what others are doing in terms of software. [...] What can the other companies do, what do they offer? What do small start-up companies offer and so on. That is interesting to me because that is, let's say, determining our future efficiency." (I44)	23
	Suppliers	Suppliers are often closely involved in digitalization processes of SMEs	"Where before you still did it mechanically, you now of course convert to all the digital things, so that in the end the difficulty arises there [...] that you then take that and turn it into a meteorological product. In other words, where you used to focus on electronics, you now focus on information technology, because now the product has to cope with the external conditions so that it works outside. [...] simply also shaped by the market and what is happening at the IT companies." (I8)	20
	Digital platforms, websites & databases	Engagement in markets with digital platforms; Information acquisition through external websites and online databases	"Internet search is a big thing for us, of course, because in this way we can see what works and what doesn't." (I23)	16
	Competitors	Trying to achieve a competitive advantage over rivals by using advanced digital tools and methods	"For example, we are now offering for the first time, and this is also our vision, the connection between a sensor with another sensor. This means that one sensor orders the goods and automatically a driverless transport system drives off and brings the goods to the production line. There is no longer a human being in between, this is classic Industry 4.0, this is where we belong. Many of our competitors are highly interested in this, I have to be careful not to tell too much, that's exactly where we are pushing forward." (I32)	17

Table A4. (continued)

	Customers	Customers as a driving force of digital-based product innovation; usage of digital technologies to open up new ways to communicate with the customer side	"Customers are a large, a very large one. In computer production, I'd say it's 90 percent, where impulses come from the customer side, and in software, I've already mentioned a percentage figure, but I've already forgotten it. So there really is a large proportion that is brought in by the customers. Sometimes the customer has to co-finance this, sometimes we say it's so brilliant that we can sell it to others as a new module, and then it's practically a real research output." (I37)	67
Innovation-related data development activities	Database activities	Using digital databases to identify potential market opportunities or as tool for knowledge management	"Our business processes very often deal with our own system, that is, they start right at the beginning. Data is stored on how precise an optic is [...]. Measurement data is entered into the system, also production data and coating data. So practically everything, the entire documentation of this optics production works via our own data management system." (I49)	56
	Software development	Software development forms an integral part of in-house R&D, or it is part of non-R&D-based innovation activity	"In terms of software, I would say 70 percent of what we do in software development for our own product is R&D, if you want, because it's always about the creation of new modules. So we're constantly developing that and maybe 30 percent are customizations for customers where I would say that's just normal service, but 70 percent are new modules or new workflows." (I37)	71
Digital competences for innovation	Data protection	Managing internal data protection; using external data protection services	"So we train our people to be scrum masters, or I could appoint someone as a data protection officer now, if it wasn't better for this one to come from extern. And yes, that's how we make sure that we somehow keep people up to date with the latest knowledge, that we always bring the latest knowledge into the company, on the one hand from the outside and then distribute it within the company, but that's actually the art of the whole thing." (I18)	17
	Training activities	Training activities based on digital technologies as well as training to support digital competences	"As I said, we provide training in the technical area primarily through our own learning workshop, so we do a lot of things there. By now, we also have an online tool for further training activities. All colleagues receive a number of work packages via this digital-based training system, so we don't have to send our people to somewhere else, but can train them online ourselves." (I49)	25
	Digital internal connections	Digital integration within and across business functions	"In terms of internal organization, we have been pushing ahead with, how shall we say, digitalization in our company for some years now. Our vision is the digital control of the entire production process, so according to this vision we control everything from ordering to purchasing to financial accounting via a software and operate it in such a way that we can also handle quality management, i.e. customers complaints, everything via it, so that we can afford to have such a flat corporate structure." (I40)	27
	Digital external connections	Interaction with external partners using digital communication technologies	"There is, well, in the past the orders came by post or fax. So now there's nothing, everything just comes by e-mail. Or with the customers, there's a, I don't know how it's called, but a platform where we pick up the orders directly, yes." (I41)	71

Table A4. (continued)

	Knowledge management	Using digital methods of knowledge management to share, protect and reuse of experience-based knowledge	"[…] if someone drops out, it's not like the tapes stand still, because we don't have them in that sense. [...] we are now using platforms that are actually available on every computer and through which our employees have access from everywhere and can generate their things accordingly. That makes us a little less susceptible when an employee leaves the company and then it's over. That is not the case." (I14)	44
	Data analytics	Using internal or external competences in data analytics	"[…] at the trade fairs, we have individual customer contact worldwide. They say, gee, I bought this product from you, but I don't like this, or this, or that. And this should be a bit stronger there, this should be a bit slimmer or more handy. [...] more ergonomic. We collect all that information. We do customer surveys, we ask our customers. These questions are then evaluated at every trade fair. [...] Evaluated in a very targeted manner [...] with failure mode and effects analyses, which we also do here." (I30)	31
	Use of digital technologies	Use of different digital technologies	"Digitalization plays a big role because we use a digital customer list, we use digital X-ray technology. Now recently we also fabricate digital models, also communication runs digitally. And that is why this is a very central tool for us." (I24)	90
	Digital capabilities / skills	In-house capabilities for using digital technologies (IT resources, digital skills, digital strategy)	"I am actually in the area of calculation, but my main area is Building Information Modeling, i.e. digital construction, which is on the rise right now. I'm also a bit involved in other digitalization activities of our company. I'm responsible for the web presence, the intranet presence, our own app, which we have for about a year now, and generally responsible for, let's say, process digitalization." (I20)	65
Innovation-related knowledge flows in digital networks	Interactions & exchanges	Use of digital technologies for more efficient knowledge exchange	"Touchscreens and other such tools are really only operating elements for us, at the moment, and now there are, for the future, as I said, these small digital pads [...] that are still to come, there is a communicative level that should improve, that should of course also stimulate the exchange of ideas, should develop fast communication, that one is simply faster, is more nimble, and can also solve things faster. You can also exchange ideas better." (I42)	44
	Trust	The role of trust in digital-based communication	"There is this discussion, this dispute, or first of all this assumption that everything that can be digitalized will be digitalized. So... I think that's only partly true, but on the other hand, you can clearly handle this exchange/network a bit via Facebook and social media, but that's somehow different than when you meet in person from time to time and sit together and exchange and talk to people face to face in real life, that simply builds trust." (I21)	13
	Diffusion & exclusion	Issues relating to the tradeoff between diffusion and knowledge protection (e.g. open-source vs. proprietary software)	"This means that our software is also open, so other sensor manufacturers can also jump in, so to speak. Simply this, not to limit ourselves, but to go beyond company boundaries [...], to create a supply chain from the manufacturer to the supplier. That first has to grow in people's minds, but that's exactly the step we're taking right now […]." (I32)	25

Table A4. (continued)

Type of innovation activity and the role of digitized information	Process innovation activity	Adoption and modification of digital technologies during the implementation of new or significantly improved business processes	"[…] it's all about innovation, I would say. I mean, in recent years, of course, [...] the development of additive, so-called additive manufacturing came up. In other words, 3D printing, not only of plastics, which we already have been doing for 20 or 25 years, but now also of metals." (I45)	92
	Product innovation activity	Digitized information forms a distinct part of new or significantly improved products and services	"And now there is a software for the new product range, an app where you have a nice little interface where you can activate all kinds of additional functions. And you can also do a system check, initial error analyses and so on. For example, if the customer has a problem somewhere, he can use the app to call it up, do a system check, and we can sometimes immediately determine what might not be working." (I38)	89
	Business model innovation	Experiences with digital business models, e.g. by integrating digitalization in a company's products or business functions in an all-encompassing sense or by switching to a databased business model by using e-commerce or digital platforms	"Actually, we are only digital. [...] This is reflected in the fact that when there is power blackout or if something happens to our network, everybody stands around or is outside. Those who can smoke, they smoke, otherwise no one has anything to do then. So without computers, nothing works. But digitalization in our company means, yes, what does it actually mean? That all information is stored digitally, that means in databases, that means ERP software, we have developed our own. All information is stored there; it can no longer be in people's heads, it has to be reproducible somewhere in databases, the whole customer and supplier management anyway, but also more and more specialist knowledge in various forms. So we have certain tools that are used, especially in software development, where certain information is stored so that it will still be available in a year's time, Ok? We have also an Issue-Tracking-System. Therefore, nothing really works in our company without software tools. The only thing I still treat myself to is a paper calendar on my desk." (I37)	53
General relevance of digitalization for innovation	Ignorance & rejection; No novelty	Opinion not to be affected by the digital transformation; Digitalization is not perceived as "novel"	"Let me start with the simplest story of digitalization, namely my business processes. So, I have an end-to-end computer system through which I manage everything. By far not everyone has that so far. I acquired it in 1999." (I45)	13
	Limits of digitalization	Problems with the external infrastructure; internal resistance to digitalization; ongoing relevance of personal, face-to-face contacts with customers etc.	"We try to do that, of course, but the human factor cannot be avoided. When you go into our production, not everything is automated, but the human must actually first place an optic in the machine and have it processed accordingly. He simply presses the button, but employees are still involved in many steps, which is why this is still a human-driven story." (I49)	47

Table A4. (continued)

	Weighing up economic pros / cons	Several SMEs are aware of digitalization potentials but are weighing up economic advantages and disadvantages of digitalization	“We don't have a proper database so far where customers are automatically assigned to a salesperson. Everything is still done a bit manually. Of course, that's anything but optimal. But then you have to say that a reasonable software package for our company costs almost 100,000 euros, which then can display everything, right? The business relationship, the customer relationship, the production relationship, if it can display and connect all these topics, you can calculate about 10,000 euros per employee, which would be about 100,000 euros in our case. Of course, this is an investment where you have to, say, you first have to find your way into the market and then you can think about it. But I think you have to do it in due time. Because if you miss the ship, at some point you can no longer catch up.“ (I3)	47

Table A5. Across-cluster percentages for sub-categories not used for clustering

Sub-categories	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Total**
Efficiency & automation	9.7%	41.9%	48.4%	100%
Corporate culture	0.0%	30.8%	69.2%	100%
Employees	11.8%	29.4%	58.8%	100%
Business owner / entrepreneur	5.3%	31.6%	63.2%	100%
Regulations & norms	15.4%	7.7%	76.9%	100%
Funding	10.0%	50.0%	40.0%	100%
University & institutes	0.0%	38.1%	61.9%	100%
Firm networks	13.0%	21.7%	65.2%	100%
Trade fairs & magazines	7.7%	38.5%	53.8%	100%
Suppliers	0.0%	37.5%	62.5%	100%
Digital platforms, websites & databases	0.0%	38.5%	61.5%	100%
Competitors	8.3%	33.3%	58.3%	100%
Customers	7.7%	30.8%	61.5%	100%
Interaction & exchanges	12.0%	28.0%	60.0%	100%
Trust	16.7%	33.3%	50.0%	100%
Diffusion & exclusion	11.1%	33.3%	55.6%	100%
Process innovation activity	14.3%	31.4%	54.3%	100%
Product innovation activity	12.9%	16.1%	71.0%	100%
Business model innovation activity	5.3%	26.3%	68.4%	100%
Ignorance & rejection; No novelty	14.3%	71.4%	14.3%	100%
Limits of digitalization	13.8%	31.0%	55.2%	100%
Weighing up pros / cons	15.0%	45.0%	40.0%	100%
Total sample share	**18.4%**	**32.7%**	**49.0%**	**100%**
Cluster label	**Beginners in digital-based innovation**	**Digital-oriented process innovators**	**Digital product/business model innovators**	

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