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RESEARCH ARTICLE

Who is leading the digital transformation? Understanding the adoption of digital technologies in Germany

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Abstract

Debates on digitalisation in Germany often refer to 'Industrie 4.0' describing a seamless and technology-driven process spearheaded by manufacturing. This view conflicts with sociological arguments, assuming highly differentiated processes of digitalisation. We review the literature and empirically test the core assumption that digital technologies relate to organisational characteristics and that adoption differs according to the type of technology. We analyse German IAB-Establishment-Panel data, which contains organisation-level information, including digital technologies. Our results show a lead of manufacturing in the adoption of digital production technologies. Regarding other digital technologies, manufacturing performs on par or is outperformed by specific service industries. Additionally, the usage of digital technologies relates to organisational characteristics, other than industry (e.g., establishment size, age, competition, employees' qualification). The relationship patterns largely persist across technologies, with some technology-specific variants. Our empirical results underline the embeddedness of digitalisation processes in Germany and underline the relevance of the technologies in question.

KEYWORDS
digital transformation, Industrie 4.0, organisational characteristics, social embeddedness, technology adoption, types of technology

INTRODUCTION

The debate around digitalisation often highlights the efforts of small, young start-up firms in high-tech industries as forerunners of radical digital transformation (Bundesministerium für Wirtschaft und Energie [BMWi], 2015; Kollmann et al., 2019; Will-Zocholl & Kämpf, 2016). In contrast, digitalisation debates in Germany rallied around the concept of 'Industrie 4.0' (Spath et al., 2013), heralding large manufacturers as champions of digital transformation, as advances in digital technology promised avenues to update the production process, reinvigorating the core strength of the German economy. However, after an initial hype that assumed a more or less seamless overarching transformation and warnings about tremendous job losses due to digitalisation (Frey & Osborne, 2013), conceptual arguments and empirical case studies show that many technologies still remain a promise in a discourse about a distant future and that the practical adoption of digital technology lags behind the overexaggerated expectations (Hirsch-Kreinsen, 2015; Pfeiffer, 2017). Sober accounts emphasise the difficulties and obstacles firms face when they try to advance digitalisation, leading to an overall incremental development (Hirsch-Kreinsen, 2019; Kirchner & Matiaske, 2019) coming up short on a radical shift. While some high-profile cases evidently engaged in digitalisation, others refrained from major changes and stuck to their conventional equipment and processes.

The view of seamless digitalisation and the 'Industrie 4.0' discourse has provoked sociological counterarguments (Hirsch-Kreinsen, 2015; Pfeiffer, 2017), claiming that digitalisation processes are inadequately portrayed as solely determined by technological opportunities. Instead, critical views emphasise that complex mutual relations between the nature of technology and the social context shape the adoption and outcomes of new technologies (Howcroft & Taylor, 2014; Liker et al., 1999). These relations lead to heterogeneous and partly paradoxical results of digitalisation according to structurally and functionally differentiated work and production processes (Hirsch-Kreinsen, 2015). While several case studies have found evidence of incremental and differentiated developments in digitisation, mostly in manufacturing industries (e.g., Hirsch-Kreinsen, 2018b; Kuhlmann et al., 2018, 2019), a broader empirical test still needs to be conducted.

Germany presents a particular case, as the debate on digitalisation strongly connects to what has traditionally been considered 'the core of the German economy', namely, large manufacturing firms and their fundamental interrelation to new technology (e.g., Baukrowitz, 2006; Kern & Schumann, 1984). The historical strength of the German economy's core sector stems from incumbent manufacturing firms coping with international competition by integrating new technology, good working conditions and industrial relations (Streeck, 1991). While the idea of the original model was challenged (Jürgens, 2004) and understood to have shifted over time (Baccaro et al., 2018; Sorge & Streeck, 2018), the ongoing 'Industrie 4.0′ debate resembles several contours of the vintage model, reinvigorating the strengths of manufacturing as the core of the German economy.

In this context, the digitalisation of manufacturing presents an opportunity to respond to international competition and regain a competitive edge as an attractive site for highly flexible and high-quality production (Icks et al., 2017; Spath et al., 2013). Early on in the debate, proponents made clear that digital technology would enable good working conditions, building on high qualifications (Agiplan & Zenit, 2015). In addition, major actors of the German industrial relations system, such as the IG Metall, became involved right from the start, shaping the discourse and incorporating labour demands into the proposed concepts (Haipeter, 2018; Ittermann et al., 2015). Therefore, digitalisation, especially the 'Industrie 4.0' transformation, could be viewed as an extension of established patterns within the core of the German economy. This model of large, incumbent, manufacturing firms with superior competitiveness, stable employment conditions, worker codetermination, high wages and skilled labour is in strong contrast to the popular view that forerunners of digitalisation are found in small, risk-taking, dynamic and innovative start-up firms in the information and communication technology (ICT) industry, finance or consulting (BMWi, 2015; Kollmann et al., 2019). This raises the empirical question of which industries and organisational characteristics are associated with a higher probability of digital technology adoption.

Furthermore, the terms 'digitalisation' and 'digital transformation' suggest a unified, overarching process, not only across firms but also across very different computer-based technologies. It is often implicitly assumed that these technologies are driven by similar impulses and eventually converge into a general pattern. In fact, many terms in the digitalisation debate merely serve as umbrella terms, comprising a vast assortment of many different forms and technologies, including widespread general-purpose technologies, new broadly applicable ICTs, and highly specific digital production systems (Bresnahan, 2010). For example, the 'Industrie 4.0' discourse revolves around production with cyber-physical systems (Schröder, 2016). However, in practice, it is often only loosely connected to explicit core technologies. Therefore, it is important to question whether digital transformation unfolds in a unified pattern or if it is heterogeneous across different types of technology. In the latter view, different technologies may be adopted only in specific organisational contexts. Whereas the manufacturing core focuses on 'Industrie 4.0' technology, other establishments such as start-ups and service establishments may adopt the remaining digital technologies. Therefore, manufacturing might not champion digital transformation as a whole, but merely specialise in particular technologies, while other establishments, especially in high-tech nonmanufacturing industries, adopt other more general digital technologies. Differences in the usage of specific technologies have rarely been addressed thus far (Arntz et al., 2016b).

This study engages with the view that digitalisation unfolds heterogeneously across organisational contexts and different types of digital technologies. The main reason for this is that technology adoption is embedded in organisational contexts that are shaped by social and economic relationships. Our argument is in stark contrast to concepts of 'Industrie 4.0' in Germany, which stress technological opportunities and disregard complex organisational heterogeneities. Further, we argue that simplistic views of digitalisation as the adoption of a homogeneous set of technologies fall short. In this vein, we review the extant literature on heterogeneity across organisational characteristics and different types of technologies to formulate assumptions to guide our empirical analysis. We followed our two main research questions: (1) What organisational characteristics are associated with the adoption of digital technologies in German establishments? (2) Are different types of digital technologies adopted in specific organisational contexts?

This study extends the existing literature by providing a comprehensive, quantitative investigation of numerous assumptions that the research field has so far articulated but only tested in rather small case studies. Using recent data from the German IAB Establishment Panel, we consider a set of organisational variables: industry, establishment size, competitive pressure, qualification structure, commitment to a collective bargaining agreement and worker codetermination in the establishment. We further distinguish three different types of technology: general-purpose technologies, industry-neutral ICTs, and industry-specific production technologies.

The remainder of the paper is structured as follows: 'State of the Art and Theory' describes explanations and previous findings on differences in the adoption of digital technologies by organisational characteristics and types of technology. 'Data, Variables and Methods' expounds on the methodology and results are presented in the 'Results' section. The last section discusses the results and draws conclusions.

STATE OF THE ART AND THEORY

Differentiated technology adoption by organisational characteristics

Building on the 'Industrie 4.0' debate (Spath et al., 2013) and previous concepts of a core of the German economy that consists of large manufacturing firms with high competitive pressure and stable employment structures (Streeck, 1991), as well as on assumptions about small, flexible and innovative firms that drive digitalisation (Kollmann et al., 2019; Will-Zocholl & Kämpf, 2016), we consider several organisational characteristics that potentially relate to the adoption of digital technologies.

Industry

Although digital transformation has embraced all industries in the economy, specific differences between them can be expected. Industries are defined not only by the goods and services they provide but also by the application of core technologies and processes. According to the particular process structure, there are different fields of application and uses of digital technologies as well as limits and problems regarding their realisation (Hirsch-Kreinsen, 2015, p. 23).

The 'Industrie 4.0' debate emphasised the importance of digital technologies for the manufacturing industries (Pfeiffer, 2017), in particular, to achieve the aim of (partly) self-organised production systems (smart factories). Hence, in the German manufacturing industry, cyber-physical production systems and the automation of manual work are considered core technologies and processes (Lerch et al., 2017; Spath et al., 2013). In contrast, knowledge-intensive industries (e.g., business consulting and market research institutes) focus on technology that complements highly skilled knowledge work, such as algorithmic software, big data analytic tools, cloud computing, online platforms and shop systems (Arntz et al., 2016b). In service industries (e.g., sales and restaurants), technologies that complement the performance of low- and mid-skilled services, which comprise a large number of interactive and social tasks, are more relevant (e.g., mobile devices). On the other hand, in healthcare, many tasks are regarded as difficult to substitute with technology because of the importance of social interactions; however, working conditions are nonetheless comprehensively affected by the implementation of digital technologies, such as health monitoring systems (Apt et al., 2018). Special attention must be paid to the ICT industry, where a particularly high level of ICT adoption is expected. Most digital technologies emerge in this industry, and ICT establishments are often among the early adopters of these technologies because they have the knowledge and fondness to do so (Will-Zocholl & Kämpf, 2016). Therefore, ICT establishments are often the main drivers of digital innovation processes (Bertschek et al., 2010; Dolata, 2015).

Empirical studies have confirmed that the application of digital technology varies across industries. According to the overall indices of digitalisation, the ICT industry is the most digitalised, followed by knowledge-intensive service providers (e.g., management consultancy, market research and the media industry) and finance and insurance industries. The automotive and healthcare industries are the least digitalised (Deutscher Gewerkschaftsbund [DGB], 2017, p. 15; BMWi, 2018b). Arntz et al. (2016b) found that the service industry identifies and uses modern digital technologies slightly more often than manufacturing as a central component of its business model. Therefore, we assume that manufacturing industries and some nonmanufacturing industries adopt digital technology at equal rates, whereas some nonmanufacturing industries lag behind, completing a highly diverse pattern across industries.

Establishment size

Several theoretical arguments suggest that larger establishments are more likely to use digital technologies than small establishments (Hirsch-Kreinsen, 2015, p. 23). The main reason for this is that larger establishments command more resources to facilitate the implementation of digital technology, whereas smaller establishments are likely to face several obstacles. Small- and medium-sized establishments may not have a budget or the possibility of funding costly investments in digital technologies. Apart from the costs of acquiring modern technologies, additional costs may arise from service and maintenance or from training employees who apply these technologies. Small establishments may also lack (highly skilled) IT employees and may face more severe problems in recruiting them, despite these employees being necessary to introduce and run new technologies (Icks et al., 2017, p. 2; Schröder, 2016, p. 4; Schöpper et al., 2018, p. 41). Consequently, investments in technology and feasible new production methods are likely to be deferred, particularly in small establishments. Furthermore, process structures in large establishments are more likely to allow efficient application of digital technologies due to more standardised functions and subdomains, and due to the larger scale of production (Hirsch-Kreinsen, 2015, p. 23). In contrast, small- and medium-sized establishments may hardly expect any productivity advantages and cost reductions, and may also see little potential in offering new products and services (Arntz et al., 2016b). Many small establishments produce individual items according to special customer requirements and operate in niche markets where historically grown employee knowledge is necessary. In combination with the often low degree of automation in small establishments, the modern concepts of 'Industrie 4.0' and digital technology are hardly adaptable (Ludwig et al., 2016, p. 73). Normative pressure to adopt digital technologies might be substantially higher for larger establishments as they are more involved in discourses on innovation and depend to a larger extent on the legitimacy granted by their current activities (DiMaggio & Powell, 1983).

Empirical research supports the popular assumption that the adoption of advanced digital technology is more common in larger establishments (e.g., BMWi, 2018b; Icks et al., 2017; Saam et al., 2016; Schröder, 2016; Wischmann et al., 2015; Zentrum für Europäische Wirtschaftsforschung [ZEW], 2015). Thus, the use of digital technology gradually increases with establishment size. This relationship holds true for most types of digital technologies. While basic ICTs, such as laptops email, and the Internet, are used irrespective of establishment size, the differences between large and small establishments have become more evident with the increasing complexity of technologies. Big data and cloud computing technologies, human resource management tools, computer-aided facility management software and enterprise resource planning (ERP) systems exhibit the largest differences by establishment size, particularly if establishments have more than 200 employees (Helmrich et al., 2016; see also Ahlers, 2018). Based on the literature on establishment size, we assume that larger establishments tend to adopt digital technologies more often.

Establishment age

The age of establishments could have an impact on the adoption of digital technologies due to the inertia of organisations, which tends to increase with age and is favoured, for example, by the investments already made. This inertia often leads to the disappearance of organisations (Hannan & Freeman, 1984). In this understanding, new forms of organisations can emerge, for example, through technological change, but older organisations often do not offer the necessary flexibility to develop and expand these new technologies (Woywode & Beck, 2014, p. 261). Mintzberg's (1979) structural archetypes and their innovative potentials have similar implications. In his understanding, successful organisations design their structures to match their situations. Technology start-ups tend to follow the archetype of adhocracy and are very flexible, open to radical innovation, and able to survive in volatile environments (Lam, 2006, p. 119).

It can be observed that newly founded establishments (start-ups) often operate at the forefront of digitalisation, developing and introducing digital technology or adopting it early on. Many of today's most successful tech companies are comparably young. Empirical research reports that approximately one-third of all start-ups in Germany are active in the ICT industry (Kollmann et al., 2019) and that the comparatively young ICT industry, in particular, is highly digitalised (BMWi, 2018b). Regarding the literature on establishment age, we assume that younger (more recently founded) establishments are more likely to adopt digital technologies.

Qualification structure

The literature on the digital transformation of work has identified changes in the structure of the required qualifications and tasks as a major consequence of digitalisation. The focus often relies on highly skilled employees because it is assumed that high skills are required to make use of the opportunities of digital technology (Arntz et al., 2016a; Hammermann & Stettes, 2016). Existing theories predict either a general upgrading of the skill structure or polarisation of the skill and wage structure (Hirsch-Kreinsen, 2015). Work could become more demanding owing to the enrichment of work when work processes are complemented by the application of digital technologies. Accordingly, the theory of skill-biased technological change stresses the increasing demand for (highly) skilled workers (Autor et al., 1998). Alternatively, the 'task approach' predicts a polarisation of the wage and employment structure because jobs with intermediate wage levels entail a relatively large number of routine tasks that are particularly likely to be substituted by technology (Acemoglu & Autor, 2011). Based on expert assessments of the task content of occupations, previous studies have shown that the likelihood of substitution is highest among occupations with low and intermediate skill requirements and that substitutability generally decreases with increasing skill requirements (Dengler & Matthes, 2018; Frey & Osborne, 2013). Drawing on this material, we assume that establishments with a higher share of highly skilled employees are more likely to adopt digital technologies than are establishments with less-skilled employees.

Competitive pressure

Digital transformation is associated with the potential to enhance competitiveness across a wide range of industries. In the manufacturing industry, the strong development of robotics and sensor technology is an advantage for advanced information flow that optimises the production, supply chain, and quality of products. In addition, for all industries, advantages can be achieved from modern communication and cooperation possibilities through digital technology, which enables better networking among employees, facilities, logistics, products, and customers (Arntz et al., 2016b). Numerous sources refer to the new availability of data in real-time, which is considered a competitive advantage (Bundesministerium für Arbeit und Soziales [BMAS], 2016, p. 16; Ittermann et al., 2015, p.15; Schröder, 2016, p. 6). Hence, if establishments ignore these technologies, competitive disadvantages can occur, which can under certain circumstances lead to disruptive changes in captured market share (Bower & Christensen, 1995). Therefore, establishments in competitive environments will usually respond to promising technological innovations by introducing these technologies themselves. Previous findings show that 37% of German establishments expect competitive advantages due to digital offerings to customers, a goal that can be achieved by digital technologies (BMWi, 2018b, p. 52 ff.).

Particularly with regard to Germany, many publications emphasise the necessity of implementing digitalisation strategies for the country to remain internationally competitive in terms of digital change and 'Industrie 4.0' concepts, that is, extensive technological interconnection (Agiplan & Zenit, 2015, p. 41; BMAS, 2016, p. 21; Lerch et al., 2017, p. 2; Wischmann et al., 2015, p. 28). This would most notably affect the German manufacturing industry (Schröder, 2016, p. 9 ff.). However, it has been shown that only approximately one-fifth of all medium-sized establishments have a comprehensive digitalisation strategy that also includes interconnection and data exchange among systems, processes and products. Among the establishments that follow such a strategy, only 13% state that they have implemented it due to competitive pressure (Saam et al., 2016, p. 20 ff.). Icks et al. (2017, p. 21 ff.) reported a similar situation in the medium-sized manufacturing industry, suggesting that competitive pressure is only one among many reasons for the adoption of digital technologies. Building on this literature, we assume that establishments facing higher competitive pressure are more likely to adopt digital technologies than those facing lower competitive pressure.

Industrial relations (works councils and collective bargaining)

Works councils can play a decisive role in successfully implementing new technology, as consultation procedures enable a joint decision-making process between employees and management (Sorge & Streeck, 1988; Streeck, 1991). Hence, unions in Germany recently initiated ambitious projects with the aim of proactively shaping digitalisation processes by activating works councils (IG Haipeter, 2018; IG Metall, 2017). Work councils may intervene to ensure that new technologies are implemented in a worker-friendly manner, particularly to avoid job losses, the intensification of workloads or extensive monitoring. However, work councils also have the right to block or slow the implementation of new technologies in certain cases. Due to § 87 Abs. 1 Nr. Six of the 'Betriebsverfassungsgesetz', work councils can veto implementation whenever technology designed to monitor the performance and behaviour of employees is implemented (Kuhlmann et al., 2019).

Additionally, collective bargaining agreements can affect the adoption of digital technology. Unions may try to advance the adoption of new technologies and shape their implementation in a manner that is beneficial to members and employees in general. In the public sector, for example, the union 'verdi' calls for collective bargaining agreements to address digitalisation together with employees (verdi, 2018). Additionally, the large manufacturing union IG Metall engaged in the 'Industrie 4.0' discourse quite early and embraced digital transformation as a chance to connect to its own political goals such as training programmes, better wages and working-time flexibility (IG Metall, 2017; Ittermann et al., 2015). However, unions could also attempt to slow the introduction of new digital technologies to prevent potential job losses due to substitution effects.

Empirical evidence shows that works councils have surprisingly rarely shaped technology adoption in rationalisation processes in the past, but that codetermination regarding new work arrangements ('Mitbestimmung und Arbeit 4.0') is now on the agenda of unions and works councils. As a result of globalisation and the emerging trend toward rationalisation and outsourcing, since the mid-1990s, work councils have primarily been tasked with protecting locations and jobs (Dörre, 2002). Constitutive approaches were aimed at the general organisation of work, but the technological circumstances were rarely questioned (Haipeter, 2018, p. 308). More recent findings show that unions and works councils are now aware of the importance of shaping digitalisation through codetermination and that they try to exercise influence through innovative, proactive practices (Ahlers, 2018; Georg et al., 2017; Haipeter, 2018; Haipeter et al., 2019; IG Metall, 2017; Klebe, 2019; Oerder et al., 2018). Condensing the ambiguous views in the literature, we assume that in the current state, there is no discernible positive or negative relationship between the prevalence of industrial relations structures at an establishment and the adoption of digital technologies.

Differentiated technology adoption by type of technology

The debate on digital transformation often implicitly suggests that the process of digitalisation is overarching and unified, not only across establishments but also across different digital technologies. Many contributions assume that the diffusion of these digital technologies is driven by similar impulses and eventually converges into a unified, general pattern of digitalisation. However, this view glosses over the fact that the term 'digitalisation' comprises various digital technologies. In line with the theoretical conjecture that the adoption and implementation of a technology depend on the organisational context as well as the type of technology (Hirsch-Kreinsen, 2015; Liker et al., 1999), it is therefore important to examine whether different types of digital technologies are adopted in specific organisational contexts.

To date, differences in the use of different types of digital technologies have rarely been addressed (Arntz et al., 2016b).

We suggest that categorising digital technologies based on their general applicability is a useful way to illustrate the potentially deviating patterns of technology adoption (see also Bresnahan, 2010). Thus, we differentiate between general-purpose technologies, such as stationary and mobile computers; broadly applicable ICTs, such as analytic and social software; and industry-specific digital production systems, such as smart factory systems (BMWi, 2018a). As we will expound, processes of digitalisation are likely to differ along these categories, which often are subsumed under the umbrella term of 'digitalisation'.

Computers can now be considered as a well-established general-purpose technology that is widely adopted in all types of establishments. In contrast, the 'Industrie 4.0' discourse revolves mainly around production with cyber-physical systems (Schröder, 2016), and the discourse on knowledge-intensive firms highlights modern ICTs, and software (Arntz et al., 2016b). These discourses indicate that different technologies may be adopted in specific organisational contexts. It follows that manufacturing might focus on 'Industrie 4.0' production technologies, whereas ICT start-ups or establishments in service might implement other digital technologies.

The conjecture that technology adoption varies across different types of technology contributes to questioning the general claim that manufacturing leads to digital transformation, as stated by the 'Industrie 4.0' discourse (Spath et al., 2013), because it may apply only to a particular type of digital technology. In this 'Industrie 4.0' discourse, manufacturing establishments adopt new technologies more frequently as compared to nonmanufacturing establishments with the type of technology and organisational characteristics being of minor importance. However, in the past, the prominent role of manufacturing was rooted in specific organisational characteristics. This was the ability of large firms facing international competition and the strong involvement of workers and unions, to adopt innovative technology (Streeck, 1991). In this respect, following the outlines of a more sociological view of digital transformation (Hirsch-Kreinsen, 2015; Pfeiffer, 2017), we argue that technology adoption is highly dependent on organisational characteristics, which if we take this position seriously, extends beyond the distinction between manufacturing and nonmanufacturing.

Therefore, we argue that what has been described earlier as a special interrelation between manufacturing and digital technology might stem mostly from the underlying organisational characteristics across industries. Hence, manufacturing establishments might not champion digital transformation as a whole, as they merely specialise in particular digital technologies. At the same time, other establishments, especially those from high-tech nonmanufacturing industries, might extensively adopt more general digital technologies. More specifically, while the view of the leading role of manufacturing compared with other industries, as well as the subordinate importance of other organisational characteristics, is likely to be adequate regarding industry-specific production technologies, it might not apply to more generally applicable digital technologies. Instead, more generally applicable digital technologies might have a higher probability of adoption in other organisational contexts, following the general assumptions outlined above (see section 'Differentiated technology adoption by organisational characteristics').

Digital technologies of the so-called third wave of industrialisation have in common that they provide computer-based assistance in aspects of information and communication, which are features that excel not only in manufacturing but also in service industries (BMAS, 2016). Hence, early adopters of these technologies could be smaller more recently founded establishments across industries (BMWi, 2018b). For example, knowledge-intensive establishments in finance often rely on analysing software and algorithms, cloud computing or online platforms (Arntz et al., 2016b). Therefore, we expect organisational heterogeneity to be most pronounced for digital technologies that are widely applicable across industries, which could be called ‘industry-neutral technologies’. Since these technologies could, in principle, be adopted regardless of a specific industry, their usage could provide an indication of a general pattern of digital transformation.

In summary, we assume that associations with organisational characteristics vary across different types of technologies. We distinguish between three types of digital technologies: general-purpose technologies, industry-neutral technologies with the purpose of enhancing information and communication and industry-specific technologies enhancing physical production. Although we would expect widespread adoption of general-purpose technologies for industry-neutral technologies, we expect adoption in smaller, more recently founded establishments and various nonmanufacturing industries. We expect that industry-specific technologies will be adopted in manufacturing, particularly in large establishments with a higher share of skilled employees.

DATA, VARIABLES, AND METHODS

Data

The IAB Establishment Panel is a representative annual survey of German establishments that provides information on establishments' characteristics and human resource practices (Ellguth et al., 2014; Fischer et al., 2009). The sample unit is the establishment, which refers to a firm's head office or local subsidiary. The survey sample is based on employment statistics as of June 30th of each year and covers all establishments with at least one employee liable to social security. The sample is random and stratified according to industry, region, and establishment size. Approximately 16,000 establishments participate in the survey annually. For our empirical analyses, we used the cross-section from 2017 because it covered establishments' application of modern digital technologies for the first time. The sample included 15,108 establishments that provided information on the application of digital technologies.

Variables

The dependent variable of interest was whether establishments used different digital technologies. The survey captures this information for nine digital technologies, which we categorise into ‘General-purpose technology’, ‘Industry-neutral technologies’, and ‘Industry-specific technologies’. The respective dependent variable takes a value of zero when the technology is not used or a value of one when the technology is used by an establishment. These three categories entail the following technologies:

General-purpose technologies:

- IT-supported work equipment (e.g., stationary computers, electronic cash registers, and CAD systems).
- Mobile devices in the establishment (e.g., laptops, notebooks, smartphones, tablets, and data glasses).

Industry-neutral technologies:

- Software, algorithms or Internet interfaces for IT-based optimisation of business processes (e.g., big data analytics and cloud computing systems).
- Social networks for personnel recruitment.
- Social networks for internal and external communication.
- Digital contracting (e.g., internet platforms, crowd-working).
- Digital sales channels for product distribution (e.g., Internet platforms or online stores).

Industry-specific technologies:

- Programme-controlled means of production that continue to require indirect control by humans (e.g., industrial robots or CNC machines).
- Networking and data exchange between equipment, processes, and products (e.g., smart factories, drones, cyber-physical systems, Internet of Things, and self-driving equipment).

We assume that establishments' adoption of these technologies depends on several organisational characteristics. The establishment size was differentiated into four classes with respect to the total number of employees in the establishment (less than 10, 10–49, 50–249, and 250 or more). We considered 19 industries, 4 in manufacturing and 15 in nonmanufacturing, comprising the private and public sectors (see Figures 2–5). The age of establishment was categorised into four groups: foundation before 1990, foundation in the 1990s, foundation in the 2000s, and foundation since 2010. Industrial relations are considered by the non-/existence of collective bargaining agreements at the industrial or establishment level and by the non-/existence of worker codetermination by a works council. An establishment's competitive situation is captured by a self-assessment of competitive pressure and by a statement of whether the establishment exports goods internationally. We considered the qualification structure of the workforce by differentiating the establishments' share of low-skilled workers (no occupational degree), qualified workers (occupational degree), and highly qualified workers (university degree). Furthermore, we included several control variables that might be related to technology application in establishments: location in East or West Germany, share of women, share of older workers (50 and older), and shares of different types of flexible employment (i.e., part-time workers, marginal employees, and fixed-term contracts).

Methods

To identify the organisational characteristics associated with the adoption of digital technologies by establishments, we estimated probit regressions. Marginal effects are reported to evaluate the effects of establishment characteristics on establishments' probability of using the respective technologies. The IAB establishment panel allows for the consideration of a comprehensive set of explanatory variables (see section 'Variables'). As we consider several establishment characteristics in the analysis, the respective associations can be interpreted to represent relationships that exist among otherwise similar establishments. This is particularly relevant regarding the shares of qualification groups in an establishment, as they are usually correlated with the structural characteristics of establishments due to the selection of workers into establishments.

RESULTS

Adoption of digital technologies in manufacturing and nonmanufacturing

The descriptive analysis shows large differences in the adoption of different digital technologies among German establishments (see Figure 1). While the use of stationary computers and mobile devices is widespread among establishments (95% and 86%, respectively), other—in principle widely applicable—technologies are far less common. Computerised process optimisation was applied in approximately 44% of the establishments. This category covers a broad range of software and interfaces such as big data analyses, cloud computing systems, and ERP software. Social networks are applied by approximately 32% of establishments for internal and external communication and by approximately 18% for the recruitment of workers. Digital processes for awarding contracts and digital sales channels were applied by approximately 20%

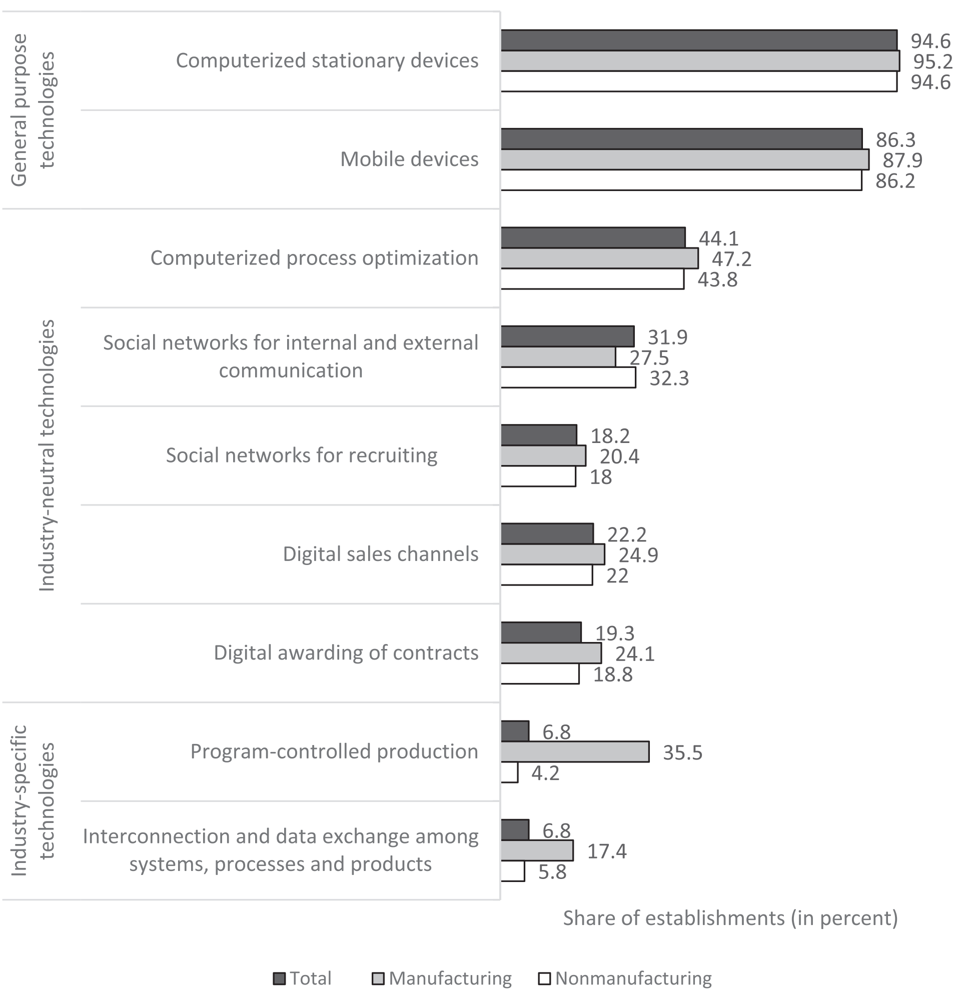

FIGURE 1 The adoption of digital technologies in manufacturing and nonmanufacturing. *Source*: IAB Establishment Panel 2017, own calculations.

of German establishments. In comparison, the use of production technologies is much less widespread. Approximately 6.8% of the establishments used programme-controlled production and/or interconnected systems and processes.

Furthermore, we distinguish the adoption of digital technologies between manufacturing and nonmanufacturing establishments, as the 'Industrie 4.0' debate suggests that manufacturing plays a driving role in Germany's digitalisation (Spath et al., 2013). With the exception of social networks for communication, the considered digital technologies are more widespread in manufacturing establishments than in nonmanufacturing establishments, but the differences are small for most technologies. This is different for production technologies: programme-controlled production is applied by approximately 36% of establishments in manufacturing, but only by approximately 4% in nonmanufacturing. Similarly, interconnected systems and processes are used by approximately 17% of manufacturing establishments and by 6% of nonmanufacturing establishments.

The results show that technologies other than general-purpose ones have not been comprehensively adopted across German establishments. This applies in particular to 'Industrie 4.0' technologies such as interconnected systems, which counters the notion of a rapid and disruptive dissemination of these technologies. Hence, establishments that apply digital technologies are likely to be selected based on their specific organisational characteristics. Additionally, the distinction between manufacturing and nonmanufacturing establishments seems to be instructive regarding highly industry-specific production technologies but not for more general technologies, which are likely to depend to a greater extent on nuanced organisational characteristics.

Differentiated adoption of digital technologies

Stationary computers and mobile devices are widespread among establishments (see Figure 1), limiting the scope of organisational heterogeneity regarding their adoption. These general-purpose technologies are not used significantly more often in manufacturing industries than in most nonmanufacturing industries (Figure 2). However, there is no significant variation in the use of stationary computers across industries and several nonmanufacturing industries are prominent in the application of mobile devices. This applies by far to establishments in information and communication, as well as in financial services, and to a somewhat lesser extent in construction, logistics, and economic and scientific services. Mobile devices are least likely to be used in hotels and restaurants.

There were two further findings regarding the use of stationary devices. The probability of applying stationary computers increases with establishment size and with higher-qualified workers in the establishment. Other organisational characteristics, such as establishment age, competitive pressure and industrial relations, are not associated with the application of stationary computers, probably because they are used universally.

There is somewhat more heterogeneity in the application of mobile devices across establishments. We find that larger and more recently founded establishments are more likely to adopt this type of technology. There is a strong positive association between the share of highly qualified employees in the establishment and the application of mobile devices. The probability of using mobile devices is also higher in establishments with high competitive pressure, and in exporting establishments, which are assumed to face more intensive competition than nonexporting establishments. Collective bargaining agreements and works councils do not make a difference.

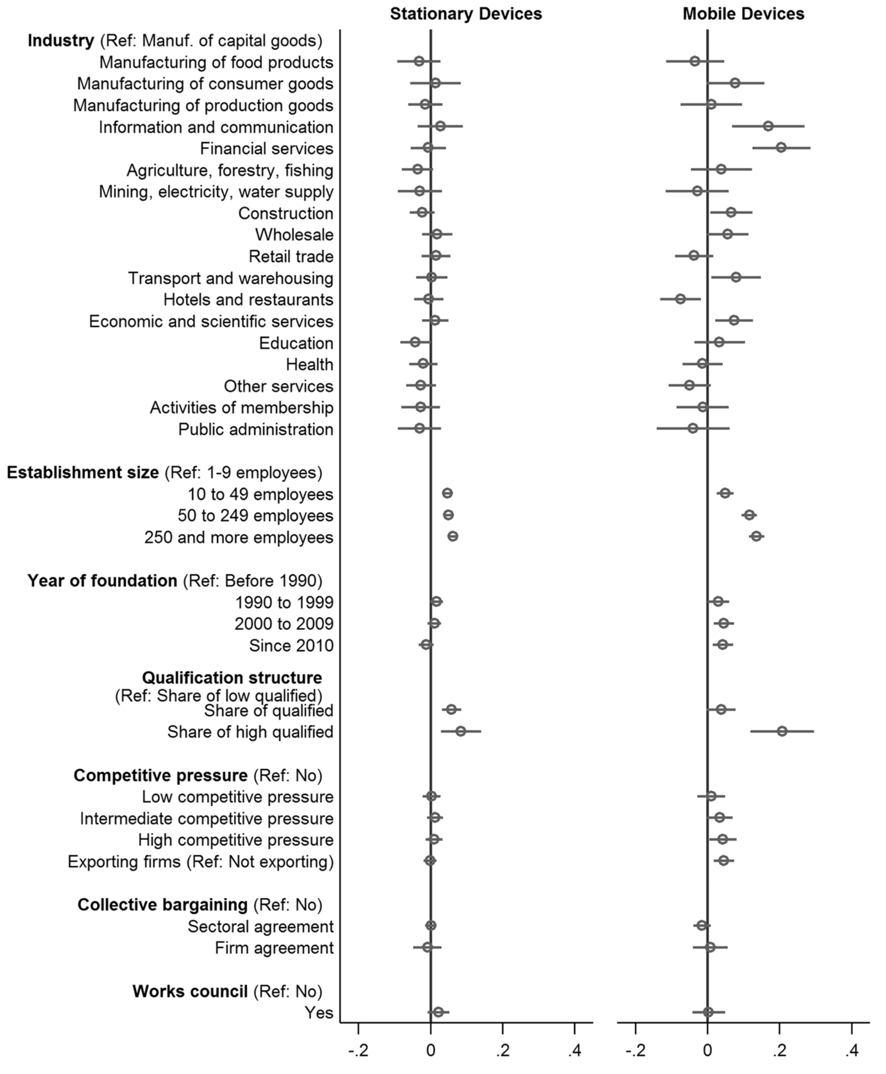

FIGURE 2 Probability of general-purpose technologies by organisational characteristics. Circles represent coefficients from probit regressions. Spikes represent confidence intervals at the 95% confidence level. Control variables: age (share of employees older than 50 years), gender (share of women), employment (share of full-time, part-time and marginal employment, and share of fixed-term employment) and location (East Germany or West Germany). *Source*: IAB Establishment Panel 2017, own calculations.

Measures of computerised process optimisation have become a core area of progress in digital technology in recent years. Almost half of the establishments in Germany used them (see Figure 1). These technologies comprise software, algorithms, and internet interfaces for process optimisation, including big data analyses and cloud computing systems. A prominent example of such a technology is SAP ERP software, which is used to optimise the quantities and timing of inputs and outputs of production and establishments' services. SAP, one of Germany's most successful technology establishments, provides this software. Furthermore, we analysed establishments' application of digital contracting and sales channels, which are similar to software for process optimisation because they organise specific parts of the stream of inputs and outputs online.

Overall, we observe similar findings regarding these three digital technologies, which are industry-neutral and therefore applicable across different industries (Figure 3). While most of the examined industries have a similar probability of applying these technologies to manufacturing, there are several nonmanufacturing industries with higher adoption and some with lower adoption of the respective ICTs. The application of all three technologies is, by tendency, the most widespread in the information and communication industry, and finance.

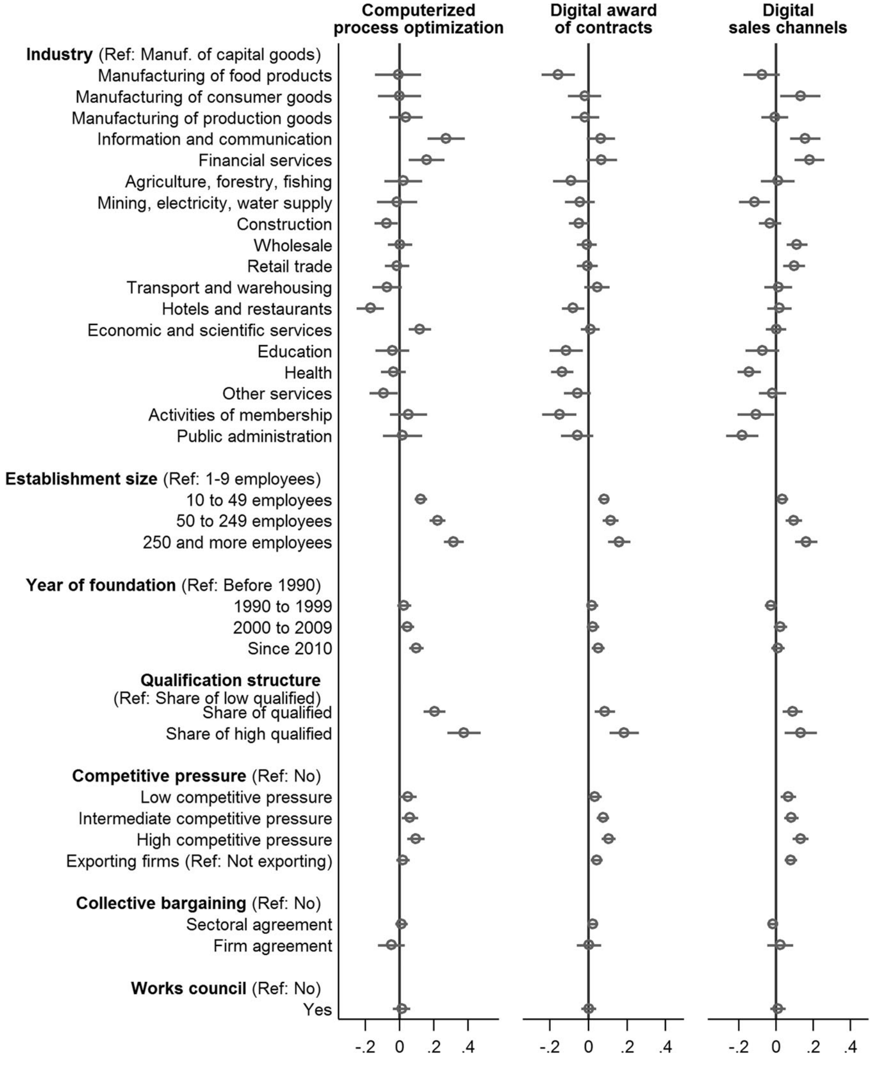

FIGURE 3 Probability of industry-neutral technologies by organisational characteristics: process optimisation. Circles represent coefficients from probit regressions. Spikes represent confidence intervals at the 95% confidence level. Control variables: age (share of employees older than 50 years), gender (share of women), employment (share of full-time, part-time and marginal employment, and share of fixed-term employment) and location (East Germany or West Germany). *Source*: IAB Establishment Panel 2017, own calculations.

However, each of these technologies has a specific pattern of industrial adoption. Regarding the use of process optimisation, there is a higher probability of its application in scientific and professional services and a lower probability for hotels and restaurants. Digital awarding of contracts is significantly less likely in the manufacturing of food products, hotels and restaurants, education, health and nonprofit organisations. Digital sales channels are particularly likely to be used in the production of consumer goods, wholesale, trade, information and communication, and financial services. They are less likely to occur in mining, health, nonprofit organisations and the public sector (Figure 3).

The larger the establishment, the more likely it is to adopt industry-neutral technologies. Furthermore, the probability of application is higher for establishments founded in the two most recent decades, but not for establishments founded in the 2000s or the 1990s than for even older establishments. Regarding the qualification structure, we find higher probabilities of technology adoption in establishments with higher shares of qualified and highly qualified workers. Higher stated competitive pressure and export activity are associated with significantly higher probabilities of using software for digital contract awarding and digital sales channels, but not for general process optimisation. There are no decisive differences between establishments with or without collective bargaining and those with or without a works council.

Regarding the use of social networks, only a few significant differentials exist by industry. Overall, social networks were not used more often in manufacturing industries than in nonmanufacturing ones (Figure 4). However, social networks are particularly likely to be used for recruitment in the information and communication industry, as well as in the finance industry and other services. Social networks are also particularly likely to be used for communication in the information and communication industry and finance, as well as in the trade industry, hotels and restaurants, professionals and other services, and nonprofit organisations. This is interesting because these industry-neutral technologies can be used principally in all analysed industries. Nevertheless, some industries adopted such sophisticated technologies earlier than others. The public administration industry lags behind.

In traditional establishments (as opposed to platform organisations), social networks are usually not part of the core processes of production or services but have the specific purpose of improving communication, marketing and personnel recruitment. Furthermore, for most digital technologies, we see significantly positive relationships with establishment size, a more recent foundation, share of highly qualified employees and extent of competitive pressure. There was no significant relationship with institutions of industrial relations.

Comments: Circles represent coefficients from probit regressions. Spikes represent confidence intervals at the 95% confidence level. Control variables: Age (share of employees older than 50 years), gender (share of women), employment (share of full-time, part-time, and marginal employment, share of fixed-term employment), and location (East Germany or West Germany).

In contrast to generally applicable technologies for information and communication, industry-specific production technologies are used more often in manufacturing industries than in most nonmanufacturing industries (Figure 5). The technologies considered comprise programme-controlled production and interconnected systems and processes. While differences by industry are larger regarding means of programme-controlled production, both types of technology considered here show very similar relations with organisational characteristics and, in particular, with establishment size and a competitive environment. Among manufacturing plants, both technologies are significantly underrepresented in the

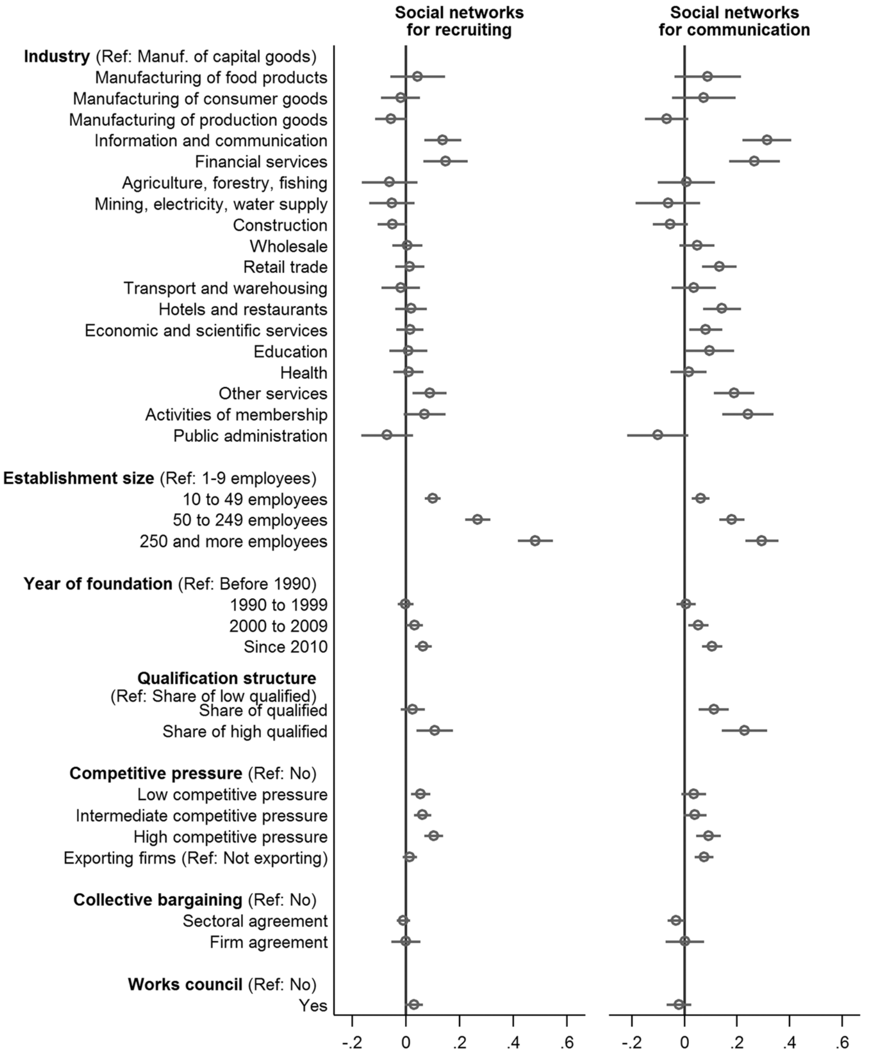

FIGURE 4 Probability of industry-neutral technologies by organisational characteristics: social networks. Circles represent coefficients from probit regressions. Spikes represent confidence intervals at the 95% confidence level. Control variables: age (share of employees older than 50 years), gender (share of women), employment (share of full-time, part-time and marginal employment, and share of fixed-term employment) and location (East Germany or West Germany). *Source*: IAB Establishment Panel 2017, own calculations.

manufacturing of food products. Compared to manufacturing, nonmanufacturing industries have a significantly lower probability of using production technologies, with the exemption of establishments in 'mining, electricity and water supply' and the 'information and communication industry', as well as agriculture regarding interconnected systems. The use of interconnected systems is particularly unlikely in the public sector (administration and education) as well as in the typical low-wage industries 'hotels and restaurants' and 'other services'.

Furthermore, the adoption of both technologies is positively associated with establishment size; the more employees an establishment has, the more likely it is to use digital production

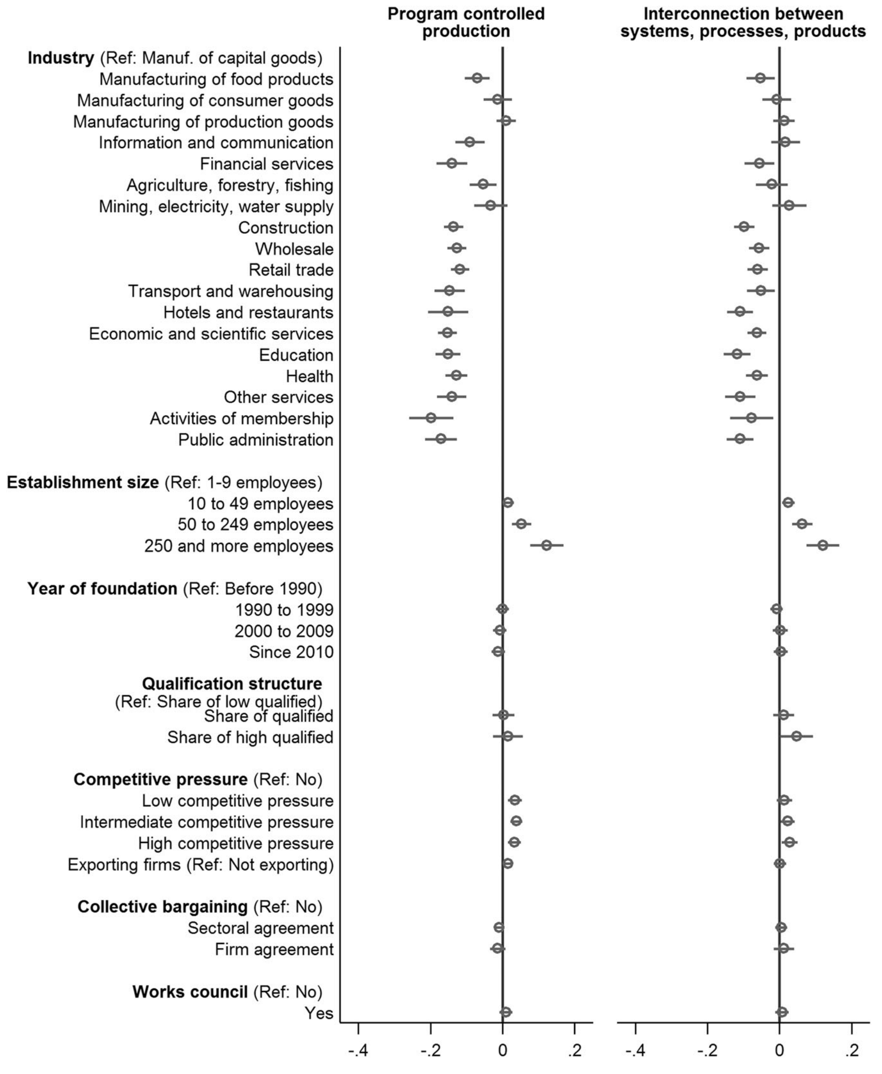

FIGURE 5 Probability of industry-specific technologies by organisational characteristics. Circles represent coefficients from probit regressions. Spikes represent confidence intervals at the 95% confidence level. Control variables: age (share of employees older than 50 years), gender (share of women), employment (share of full-time, part-time and marginal employment, and share of fixed-term employment) and location (East Germany or West Germany). *Source*: IAB Establishment Panel 2017, own calculations.

technologies. We also observed a significant positive association between competitive pressure and the adoption of programme-controlled production and interconnected systems and processes. There are no differences between exporting establishments and other establishments, thus not emphasising a particular importance of international competition. There is no further differentiation in the use of production technologies regarding other organisational dimensions, such as the age of establishment, qualification structure or industrial relations.

Interestingly, separate regressions among manufacturing and nonmanufacturing establishments reveal opposite associations with qualification structures in both the industries. While the share of qualified and highly qualified employees is positively associated with digital production technologies in nonmanufacturing establishments, it is negatively associated with digital production technologies in manufacturing. This may suggest that for these technologies, there is a pattern to substitute low-qualified labour in manufacturing, while it augments qualified labour in nonmanufacturing establishments.

DISCUSSION AND CONCLUSIONS

This study examines establishments' adoption of digital technologies depending on organisational characteristics by using data from a large employer survey in Germany. Based on sociological literature, we argue that technology adoption is embedded in organisational contexts, which are shaped by social and economic relations, and therefore, is inadequately portrayed as a seamless, overarching process that is primarily determined by technological opportunities (Hirsch-Kreinsen, 2015; Liker et al., 1999). Consequently, digitalisation is expected to be a heterogeneous and incremental process since establishments face specific opportunities and limitations according to their organisational characteristics. Furthermore, reservations and limitations of digital technology may lead to a divide between the practical adoption of digital technology and over-exaggerated expectations from the 'Industrie 4.0' discourse that started in Germany (Hirsch-Kreinsen, 2015; Pfeiffer, 2017). This debate around 'Industrie 4.0', as a comprehensive driver of development in Germany, falls short of acknowledging the heterogeneity of digitalisation processes. Several case studies have found evidence of incremental and differentiated developments in digitalisation, mostly in the manufacturing industry (e.g., Hirsch-Kreinsen, 2018b; Kuhlmann, 2019; Kuhlmann et al., 2018), we provide a comprehensive quantitative empirical test for these assumptions.

We show that differences in the adoption of digital technologies between German establishments in manufacturing and nonmanufacturing are marginal regarding generally applicable digital technologies, and are significant only for specific production technologies. The establishments' application of general ICTs is associated with a set of organisational characteristics across manufacturing and nonmanufacturing industries. This result doubts the general championship of manufacturing 'Industrie 4.0' in the process of digitalisation and indicates a much more differentiated picture. While we find that different manufacturing industries have intermediate probabilities of using most digital technologies compared with other industries, the ICT and financial services industries have the highest probability of using digital technologies. Together with the finding of a higher probability of technology application in younger establishments, we find empirical evidence that young start-up establishments in high-tech industries are at the core of current technological developments in Germany, as common views in the debate suggest (BMWi, 2015; Kollmann et al., 2019; Will-Zocholl and Kämpf, 2016). However, the importance of these industries as 'drivers' of digitalisation is put into perspective by other robust dependencies between organisational characteristics and technology adoption.

While there are some specifics about the associations of organisational characteristics with the adoption of different types of current digital technologies, several of the relationships we find have also been linked to technology diffusion and innovations in the past (Streeck, 1991) and were to some extent reinvigorated with the debate about 'Industrie 4.0'. This applies, in particular, to interrelations with establishment size, higher qualifications of workers or competitive pressure. This finding supports the theoretical descriptions of digitalisation processes as building incrementally and path dependent on previous developments in different segments of the economy, rather than the notion of comprehensive and disruptive radical change (Hirsch-Kreinsen, 2018a). Furthermore, these relationships are independent of industry differences and highly consistent across the different digital technologies that we consider. Taken together, these robust relationships are more important in shaping digitalisation among establishments than differentiation across industries. The relevance of establishment size must be emphasised, as it shows the strongest and most consistent association with technology applications in our results. The processes in large technology-intensive establishments are typically characterised by both high complexity and large batch production (Lerch et al., 2017). However, we also find pronounced differences between establishments of intermediate and small size. The findings also imply that by tendency, there are reservations or even difficulties concerning digital technologies in small establishments, establishments with high shares of low-qualified workers or a low level of competitive pressure. The reasons for this may lie in the limited opportunities to finance necessary investments but also in the reduced opportunities to benefit from such investments on a large scale.

Collective bargaining by unions and worker codetermination by works councils do not seem to systematically foster the adoption of digital technologies or systematically obstruct it. This is noteworthy, as unions engaged early in the digitalisation debate (Haipeter, 2018; Ittermann et al., 2015). This finding does not support the elevated role of codetermination in digitalisation processes, which has been stressed in the concept of 'Industrie 4.0'. This might simply follow from the fact that more technology-prone industries, such as the ICT industry, are much less embedded in the German industrial relations system. Here, relationships are likely to follow complex underlying patterns, with industrial relations posing no barrier to digital transformation. However, as Streeck (1991) points out, there may be a difference between the rapid adoption of technology and the long-term effects of its implementation. Employing participation by unions and works councils may foster high-trust solutions with better working conditions. Therefore, further research should examine how unions and works councils shape the implementation of digital technologies, for example, to limit the extent of 'Digital Taylorism', monitoring of workers, or work intensification.

While a broader view often understands digitalisation as an umbrella term and neglects the variety of technologies that it comprises, we examined several types of technologies. Overall, the observed relationships between organisational characteristics and technology adoption are highly consistent across distinct types of technologies. However, we also observed specifics in the adoption of several types of technology. General-purpose technologies, such as stationary computers and mobile devices, are applied in the vast majority of establishments. Accordingly, differentiated organisational characteristics are of low importance in explaining the adoption of these technologies. However, more widely applicable ('industry-neutral') ICTs are much less widespread. To attain a differentiated perspective on who is driving digital transformation in Germany, it is particularly interesting to examine which establishments apply these technologies because all establishments can deploy them in principle. The ICT and financial services industries are clearly the forerunners in the application of these technologies, while manufacturing lags behind. Apart from the association between the application of these technologies and establishment size and competitive pressure, there are also significant positive associations with higher shares of qualified workers and lower establishment age. Hence, we find empirical evidence for young start-up establishments in ICT as drivers of digitalisation. However, most establishments that apply generally applicable digital technologies are large in size. By contrast, industry-specific production technologies are used more often in manufacturing plants than in nonmanufacturing plants. This result is in line with the general 'Industrie 4.0' concept, which highlights new production technologies such as cyber-physical systems (Schröder, 2016). There is also a strong relationship between the size of establishments and a weak relationship with competitive pressure for these technologies. However, other organisational characteristics are associated with the adoption of production technologies to only a small extent. Notably, these new production technologies are not widespread in manufacturing. This implies that the view of the prominent role of manufacturing in the diffusion of the newest technologies is appropriate only for production technologies, while the comprehensive dissemination and implementation of 'Industrie 4.0' technologies are still a long way off.

Unlike the findings regarding industry-neutral technologies, the results for production technologies are in line with the predictions of the 'Industrie 4.0' discourse. However, several details must be noted regarding digital production technologies to assess the scope of 'Industrie 4.0' in Germany. First, the adoption of digital production technologies is not widespread even in manufacturing. Second, the nonexistence of differentiation according to collective bargaining agreements or works councils regarding production technologies casts doubt on the narrative that institutions of worker representation provide (yet) a strong voice in the processes of digitising production. Third, the observed positive associations with establishment size and competitive pressure are not singular to manufacturing plants but are present in both manufacturing and nonmanufacturing, and thus independent of the industrial distinction.

Overall, our findings underline that the recent wave of digital transformation has not progressed seamlessly and comprehensively and that the notion of a single core as the driver of digitalisation in Germany falls short. Rather, the process of digitalisation is much more differentiated. While comprehensive adoption has been reached for older digital technologies such as personnel computers, the application of newer and more specific digital technologies is confined to limited spheres, particularly in the ICT and finance industries and among large establishments that can use tools such as big data analysis for efficient use. Small- and medium-sized establishments in other industries are way behind regarding digitalisation. Start-ups in the ICT industry play a prominent role in digital transformation; however, they are also a specific, confined niche of the economy, and the dissemination of respective technologies to other contexts occurs incrementally and is highly differentiated. The heterogeneous development of digitalisation across organisational characteristics is likely to coincide with increasing differentiation and inequalities across workplaces. It is expected that the application of digital technologies will increasingly shape working conditions in the future, and that disparities, particularly between small and large establishments, will grow further. Thus far, institutions of industrial relations have not exerted balancing leverage in the process of technology adoption.

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