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Unpacking digital servitization: How its facets drive platformization and Industry 4.0

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ABSTRACT

Giving rise to both incremental and radical changes in manufacturing, digitalization is attracting major interest in servitization research. The diffusion of technologies and their adoption in business settings triggers simultaneous and interconnected phenomena that call for continuous examination of digital servitization, digital platforms, and digital production technologies in the context of Industry 4.0. While these three concepts have been conceptually assumed and qualitatively demonstrated as being interconnected, less is known about the effect of digital servitization on platforms and Industry 4.0, both key elements of the (digital) value creation sphere. This study aims to fill this gap by demonstrating whether and the degree to which digital servitization impacts manufacturers' platformization process and Industry 4.0 orientation. Using a large-scale representative data set from the German manufacturing sector containing firm-level data from 1256 manufacturers, our results show that a firm needs to establish various digital servitization capabilities, such as digital customer integration, data analytics, and advanced service offerings, before effects on digital platforms and Industry 4.0 can be evidenced. Moreover, our analysis allows conclusions to be drawn about the degree to which the three facets of digital servitization - scope, depth and extent - act as drivers of platformization and Industry 4.0.

1. Introduction

Servitization and digitalization are the major forces driving manufacturing and reshaping established logics of value creation and firm competitiveness (Kohtamäki et al., 2019; Müller et al., 2018). Servitization describes the increasing service orientation of manufacturers, who are shifting their focus from products to integrated solutions (Lightfoot et al., 2013). In parallel, digitalization generates new opportunities and brings about disruptions by enabling data-driven business models (Gradillas and Thomas, 2023). Digital technologies (DT) such as the Internet of Things (IoT), big data analytics, and cloud computing, often referred to as data-driven technologies, are central to Industry 4.0 (I4.0), enabling connected, intelligent production systems (Kagermann, 2015; Kinkel et al., 2022). These technologies also underpin the platformization of industries, allowing value creation through multi-actor digital ecosystems (Tian et al., 2022). The convergence of servitization and digitalization, commonly referred to as digital servitization (DS), has become a central topic in innovation and technology management research (Kohtamäki et al., 2019, 2020; Vendrell-Herrero et al., 2017). DS involves using DT to develop new services or enhance existing ones (Paschou et al., 2020). It enables real-time interaction, predictive service delivery, and new forms of value co-creation between manufacturers and customers (Eloranta and Turunen, 2016; Kowalkowski et al., 2013). Yet despite its potential benefits, many manufacturers face challenges in aligning technological investments with organizational capabilities and service-oriented strategies (Gebauer et al., 2021; Paiola et al., 2021).

The servitization literature emphasizes that successful transformation requires the reconfiguration of organizational resources and the development of specific capabilities (Huikkola et al., 2022; Ulaga and Reinartz, 2011). As firms embrace DT, these capabilities increasingly evolve into DS capabilities, or the ability to integrate digital tools into service design, delivery, and customer relations (Münch et al., 2022; Rönnberg Sjödin et al., 2016). Through these capabilities, manufacturers deepen customer engagement and expand the joint value co-creation sphere (Grönroos and Voima, 2013; Lenka et al., 2017). DS

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unfolds along the entire value chain, linking internal production processes with external service delivery mechanisms. Upstream, firms integrate DT into production systems, creating I4.0-related services that connect manufacturing processes with service provision (Frank et al., 2019b). Downstream, manufacturers increasingly employ digital platforms to deliver and scale services, leading to platform-based servitization (Cenamor et al., 2017; Eloranta and Turunen, 2016; Tian et al., 2022). These developments suggest that DS, platformization, and I4.0 are interlinked trajectories of digital transformation (Kohtamäki et al., 2020). Despite substantial progress, three major knowledge gaps in this field remain. *First*, there is little empirical evidence of how DS transforms upstream (I4.0-related) and downstream (platform-based) processes. *Second*, most existing research relies on qualitative case studies and is often focused on large digital pioneers such as Siemens, IBM, and General Electric (Baines et al., 2013; Gebauer et al., 2021), thereby limiting generalizability. *Third*, there is a lack of large-scale quantitative analyses that capture how the different facets of DS, namely scope, depth, and extent, relate to platformization and Industry 4.0 across the broader manufacturing base (Gebauer et al., 2021; Kohtamäki et al., 2019).

Against this background, the present study investigates the relationships between DS, platformization, and Industry 4.0 in manufacturing firms. Specifically, we examine whether and to what extent the adoption of DS practices is associated with the use of digital platforms and the use of I4.0-related technologies. To gain a nuanced understanding, we analyze three distinct facets of DS, scope, depth, and extent, assessing their differential impacts on platformization and Industry 4.0. Accordingly, we address the following research question: *What is the impact of digital servitization on the use of digital platforms and Industry 4.0 among manufacturing firms?*

This study contributes to the growing body of research at the intersection of servitization, Industry 4.0, and digital platforms, directly responding to recent calls for integrative and quantitative approaches (Biesinger et al., 2024; Cannavacciuolo et al., 2023; Minaya et al., 2024; Shen et al., 2023). The contributions are threefold. In terms of its *conceptual contribution*, we refine the conceptualization of DS by distinguishing its scope, depth, and extent as drivers of platformization and I4.0 adoption, thereby extending prior frameworks (Kohtamäki et al., 2019; Vendrell-Herrero et al., 2017). From a *theoretical perspective,* and by embedding DS in the value co-creation logic (Grönroos and Voima, 2013), we identify platformization and I4.0 adoption as key mechanisms through which co-creation occurs. Regarding the *empirical contribution*, we provide large-scale quantitative evidence on DS and related transformation based on 1256 manufacturing firms in Germany, a leading industrial ecosystem and an early adopter of Industry 4.0 (Kagermann, 2015; Liao et al., 2017). The data were collected at the end of 2018, capturing a critical pre-pandemic scenario for digital transformation ahead of the worldwide acceleration of digitalization due to COVID-19 (Kapoor et al., 2024). This setting allows the documentation of early-stage adoption of DS, digital platforms and I4.0 across different manufacturing sectors.

The paper is organized as follows. Section 2 presents the theoretical background and hypothesis formulation, integrating insights on DS capabilities, organizational learning, Industry 4.0, and their connections. Section 3 details the research design and methodology, including the data, variables, and modeling procedures. Section 4 reports the results, followed by the discussion and examination of the implications in Section 5. Section 6 concludes with the contributions and limitations of the study, and directions for future research.

2. Theoretical framework and hypothesis formulation

2.1. Digital servitization: capabilities and organizational learning

The observed phenomenon that product manufacturers are becoming product-service providers has received increasing attention in recent decades (Baines et al., 2017; Lightfoot et al., 2013; Velamuri et al., 2011). The concept of *servitization* goes back to Vandermerwe and Rada (1988, p. 312), who defined it as "*the increased offering of fuller market packages or "bundles" of customer-focused combinations of goods, services,* support*, self-service, and knowledge to add value to core corporate offerings*". A key issue of servitization is the transformation process of manufacturers (Baines et al., 2017), or the transition from a product-centric to a service-centric company (Baines et al., 2009; Matthyssens and Vandenbempt, 2010; Oliva and Kallenberg, 2003). While servitization describes a manufacturer's transformation process, the so-called Product-Service Systems (PSS) represent its output (Frank et al., 2019b), involving various stakeholders and eventually evolving into collaborative ecosystems (Dalenogare et al., 2023; Kapoor et al., 2022). Following Brandstotter et al. (2003, p. 799) "*a PSS consists of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling specific customer needs*".

There are various conceptual models that describe the servitization process in the different stages or are oriented to different types of PSS (Matthyssens and Vandenbempt, 2010; Tukker, 2004). However, authors largely agree that a manufacturer that wants to successfully manage servitization should first master the basic services and only then progress to the more advanced ones (Baines and Lightfoot, 2014). The PSS therefore becomes increasingly complex in step with the progress of the transformation process.

However, the digital advances made in the last decade have changed both the nature of the services offered (Lerch and Gotsch, 2015) and the way providers and customers interact and create value (Lenka et al., 2017). The DS literature stream has emerged from these fundamental changes, analyzing how the use of digital solutions and technologies alters existing manufacturers' service offerings and enables new ones (Baines and Lightfoot, 2014; Kowalkowski et al., 2013; Rymaszewska et al., 2017). In this context, it becomes apparent that DT are essential for the successful provision and efficient processing of advanced services (Baines and Lightfoot, 2014; Rönnberg Sjödin et al., 2016). The expected fundamental changes evidence that digitalization facilitates the significant expansion of the previous boundaries of the service business of manufacturers (Lerch and Gotsch, 2015).

The positive effect of competitive advantage resulting from service offerings (Gebauer et al., 2006) cannot be explained by a firm's resource configuration alone (Raddats et al., 2015), but is also dependent on the use of these resources with the help of specific capabilities (Raddats et al., 2019; Ulaga and Reinartz, 2011). In this context, previous work emphasizes that manufacturers must not only reconfigure their resource base (Penttinen and Palmer, 2007), but also build new capabilities to successfully enter the service business (Baines and Lightfoot, 2014; Oliva and Kallenberg, 2003). Capabilities for cultural change, innovation, partnerships building, and front-office activities, to name just a few, are needed to develop and deliver PSS (Münch et al., 2022; Raddats et al., 2019).

It is consequently anything but easy for manufacturers to move into DS. The digital capabilities required to do so, on top of conventional service capabilities, further increase the complexity of the service business (Kohtamäki et al., 2019). The most significant change expected from DS is the storage, processing, and transmission of the collected data. Given that digital devices can decouple content from the physical medium, innovations and scaling in service offerings can also come about (Münch et al., 2022). Not only can this give rise to innovative products and services, but the resulting business models can facilitate greater integration between manufacturer and customer (Kagermann, 2015; Kohtamäki et al., 2019). When manufacturers move into DS, new types of smart solutions or so-called Smart PSS can emerge (Kohtamäki et al., 2019; Münch et al., 2022). The huge amount of data and the use of suitable algorithms that generate options for new payment models (Müller et al., 2018) enable the optimization of existing processes (Frank et al., 2019b; Kowalkowski et al., 2013). Platforms and mobile devices can be used for fuller access to customers' processes, further increasing integration (Coreynen et al., 2020; Pauli et al., 2021).

Offering Smart PSS therefore requires a much deeper understanding of customer needs and a greater ability to integrate different partners than is the case with conventional PSS and even pure products (Münch et al., 2022). Manufacturers must consequently build new, digital capabilities (Lenka et al., 2017). In this context, Lenka et al. (2017) argue that these new digital capabilities are the enablers manufacturers require to expand their value co-creation sphere in line with increased customer interaction. DT such as the IoT, cloud computing, and data analytics must therefore be mastered to develop and deliver Smart PSS (Belvedere et al., 2013; Coreynen et al., 2020). Münch et al. (2022) explore DS capabilities from a socio-technical system perspective using a variety of dimensions, and combining servitization and digital capabilities. In this regard, manufacturers obviously need to construct a broad set of capabilities in the technological dimension, including data analytics tools and IoT, ensuring mastery of integration and digital platforms, which involves digital affinity and a shift in competences on the part of employees (Kinkel et al., 2023; Münch et al., 2022). Other necessary capabilities are data monetization (Ritala et al., 2024), customer management (Fliess and Lexutt, 2019), and service-oriented pricing and billing (Münch et al., 2022), illustrative of the strong customer integration of DS. Furthermore, it is stated that DS requires a more process-centered way of working, which concerns not only customer management but also organizational processes themselves (Münch et al., 2022; Paiola and Gebauer, 2020).

This increased focus on the use of DT leads to similar capabilities as those required for other digital transformations in industrial firms, prompting various authors to assume that there are convergences between DS, platforms, and Industry 4.0 (Bortoluzzi et al., 2020; Cenamor et al., 2017; Coreynen et al., 2017; Eloranta et al., 2021; Ennis et al., 2020; Frank et al., 2019b; Simonsson et al., 2020). Platformization at firm level can be defined as a manufacturer's "*shift from product thinking to platform thinking*" (Lerch et al., 2024, p. 1), such that companies begin to offer a "*new platform-based, digital product together with complementary IT services*" (Weking et al., 2020, p. 9).

From a theoretical perspective, the convergence of DS, digital platforms, and I4.0 can be underpinned by the concept of organizational learning, the theory of which analyzes and describes how an organization learns the capabilities it needs to survive in competition (Valtakoski, 2017), delivering important aspects in the context of DS (Momeni et al., 2023). Organizational learning tends to focus on and develop intra-organizational learning mechanisms (Momeni et al., 2023), explaining how information is received, processed, and stored in a company (Zhu et al., 2018). Collected experiences are transformed into knowledge, which leads to new routines and actions that align with the company environment (Easterby-Smith et al., 2000). More specifically, there are four learning processes (intuiting, interpreting, integrating, institutionalizing) that link the individual and organizational levels. They are bi-directional and connected by feedback loops (Crossan et al., 1999). This mechanism causes knowledge and capabilities to diffuse within an organization. Considering these learning processes, we presume that digital capabilities can also be transferred to other parts of manufacturers' value creation spheres through organizational learning.

In the context of business models and PSS, digital capabilities are developed by a variety of actors throughout the entire ecosystem (Kohtamäki et al., 2019; Kolagar et al., 2022; Marcon et al., 2022; Sklyar et al., 2019). Since our study focuses explicitly on the bilateral connections between manufacturer and customer, we use the value co-creation model proposed by Grönroos and Voima (2013), consisting of a provider and a customer sphere, as a conceptual basis. By offering services and PSS, manufacturer and customer processes begin to merge, creating the joint value co-creation sphere (see Fig. 1). Digital capabilities of the manufacturer further drive this interaction, allowing the joint sphere to expand Lenka et al. (2017).

We propose that when a manufacturer develops digital capabilities, these do not remain isolated but spread across their co-creation sphere by means of organizational learning effects (Crossan et al., 1999; Momeni et al., 2023). Accordingly, we argue that firms that embrace DS are more easily able to move into both platformization and Industry 4.0. This leads to an expansion of the value co-creation sphere both upstream, by means of I4.0-related services (convergence of DS and I4.0 (Frank et al., 2019b)), and downstream, by means of platform-based servitization (convergence of DS and platformization (Tian et al., 2022)). DS capabilities can thereby lead to a joint sphere encompassing both manufacturer and customer that expands from the production phase to the product's usage phase.

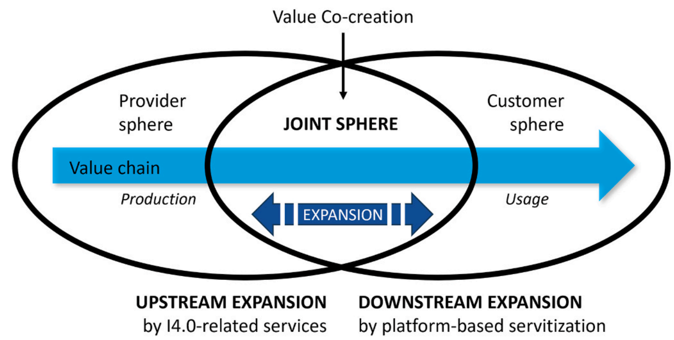

Fig. 1. Conceptual framework: the value co-creation model with upstream and downstream expansion
Source: adapted from Grönroos and Voima (2013).

2.2. Facets of digital servitization

Building on the conceptual understanding of how DS capabilities emerge and spread through organizational learning, this section addresses specific features that reveal the development of these capabilities in practice. For this purpose, we introduce the so-called 'facets' of DS, defining them as partial aspects that are able to describe the level of DS for manufacturers, and at the same time represent a bundle of required capabilities. Given that DS has to be considered as a two-dimensional construct that integrates digitalization and servitization (Lerch and Gotsch, 2015), and is simultaneously built on their convergence (Gebauer et al., 2021; Vendrell-Herrero et al., 2017), to consider the two dimensions appropriately, we chose three facets that cover a broad spectrum of capabilities a manufacturer must master.

The first facet focuses on DT adoption (Lenka et al., 2017; Münch et al., 2022), the second on the integration between provider and customer (Kowalkowski et al., 2013; Münch et al., 2022), and the third on the service portfolio itself (Baines and Lightfoot, 2014; Frank et al., 2019b; Rapaccini et al., 2023). These facets are not strictly independent of each other, although each highlights a specific partial aspect, thereby providing deeper insights into the impacts of DS that arise upstream and downstream across the value creation sphere.

Scope: A crucial capability of firms is the use of DT (Münch et al., 2022). This includes not only IoT, cloud computing, and data analytics, but also big data, artificial intelligence, and other connected solutions. In this context, each single digital solution must be technologically integrated into the firm's service offering and organizational processes (Münch et al., 2022; Paiola and Gebauer, 2020). We argue that a manufacturer's corresponding capabilities increase with every additional digital solution adopted. Consequently, the *first facet* describes capabilities to expand the technological diversity of the service offering as required, using not just one but possibly several digital solutions, which we understand as the '*scope of digital service solutions*'.

Depth: When manufacturers shift their focus from a product-centric to a service-centric offering, it is important to expand the value co-creation sphere and integrate the customer, or the recipient, into their processes (Lenka et al., 2017). This integration is therefore seen as a crucial capability of a manufacturer when offering services and PSS (Münch et al., 2022). To this effect, we assume that the deeper the integration of the recipient into the manufacturer's value creation sphere, the greater the capabilities required. A concept that takes this integration into account differentiates between type of recipient (Kowalkowski et al., 2013) and consequently between product (lower integration) and client (deeper integration). We therefore call our *second facet* the '*depth of digital service integration*'.

Extent: Another key capability of a manufacturer is the implementation and expansion of their service portfolio in terms of types of services and PSS (Baines and Lightfoot, 2014). There are servitization capabilities that enable companies to offer not just mandatory but also advanced services, and digital capabilities must be developed to offer digital as well as manual services (Frank et al., 2019b). Therefore, our *third facet* focuses on service portfolios that simultaneously integrate advanced services and digital services (Rapaccini et al., 2023), requiring higher capabilities than mandatory or manual service offerings individually. To consider all types of services, we call this facet the '*extent of the digital service portfolio*'.

2.3. Digital servitization, platformization and Industry 4.0

From the perspective of a manufacturer offering digital services, there is also the potential for using a servitization platform approach (Cenamor et al., 2017; Tian et al., 2022). This approach assumes that so-called digital product-service platforms provide the technological basis for product manufacturers to make their digital services available to customers (Simonsson et al., 2020). It is therefore an effective approach for manufacturers to use and operate their own platforms to exploit the full potential of the collected data and the resulting new service offerings (Cenamor et al., 2017).

According to the literature, a platformization approach can enhance the value of DT, especially in the context of advanced services, increasing both customer orientation and efficiency (Cenamor et al., 2017; Eloranta and Turunen, 2016). Platform-based service architectures allow manufacturers to modularize and integrate service offerings more effectively, improving scalability and customer responsiveness (Kohtamäki et al., 2020; Paiola and Gebauer, 2020). Moreover, platform offerings can exploit complementarities and substitution effects (Cusumano et al., 2015). Advocates of this perspective, Cenamor et al. (2017), Eloranta et al. (2021), Simonsson et al. (2020), Tian et al. (2022), assume that it is extremely advantageous for manufacturers providing digital services to operate their own digital platforms, implying that they must increasingly move into platform-based servitization.

The relationship between DS and the supply and use of digital platforms is discussed in the literature, mainly in literature reviews and case studies (Cenamor et al., 2017; Paiola and Gebauer, 2020; Paschou et al., 2020; Simonsson et al., 2020). There is generally broad agreement that the process of platformization facilitates the supply and use of digital services. Pirola et al. (2020) state in their literature review that platforms are needed to support DS. Based on Italian case studies and a case study in Sweden, Garzoni et al. (2020) show that digital services rely on IoT and digital platforms, respectively, and Simonsson et al. (2020) show how digital product-service platforms can easily be built with a modular platform approach, thereby supporting DS.

A digital product-service platform as the key element of a modular service architecture enables firms to create a wide portfolio of services with easily interchangeable modules (Cenamor et al., 2017; Meyer and Lehnerd, 1997). They can thereby tailor service offerings to customer needs, which translates into customization, achieving customer satisfaction and improved customer relations, giving firms a strong competitive advantage. Furthermore, platform-based digital and modular service offerings increase flexibility, are easily scalable, and can reduce costs (see product platforms, e.g., in the automotive industry (Bask et al., 2010)), thereby improving operational efficiency. Based on a case study, Eloranta and Turunen (2016) show that digital product-service platforms facilitate service delivery and improve relationships with stakeholders. Digital platforms also make it easier to communicate and interact, and to coordinate activities and distribute responsibilities among different actors, fostering value co-creation (Cenamor et al., 2017). Additional benefits are identified by Kohtamäki et al. (2020), such as enhanced data acquisition, data warehousing, and big data analytics, which is in line with Paiola and Gebauer (2020), who state that digital platforms help harness and leverage customer data. This data can then be used to improve and expand the service portfolio with advanced, data-driven, and customized services.

In short, digital platforms can be seen as a way to overcome the challenge of the service paradox, whereby despite investing heavily in their service business, manufacturers often fail to achieve the expected financial success (Cenamor et al., 2017; Gebauer et al., 2006; Jha et al., 2016). Platformization enables manufacturers to mitigate this paradox by improving customization, operational and organizational efficiency, and advanced data-based offerings. Notably, based on a broad literature review, Paschou et al. (2020) even conclude that technology-enabled platforms and business models are part of DS. Consequently, our first hypothesis is:

H1. The higher the level of digital servitization, the more likely the company is to use digital platforms.

DS not only paves the way for new capabilities for manufacturers but also impacts the transformation process from a product-centric to a service-centric firm. In this context, Frank et al. (2019b) distinguish three levels of service offerings of product manufacturers based on their degree of digitalization: manual services, digital services, and I4.0-related services. The first largely do without DT, only making use of basic applications such as CRM software. The second describe service offerings that generate added value for customers, using moderately advanced DT such as cloud computing and apps as solutions, integrated with a physical product. In contrast, I4.0-related services focus on both internal Industry 4.0 processes and external service offerings for customers and are able to generate added value for both manufacturers and customers through digital networking. Some authors focus on the interlinkages between digital service offerings and I4.0, which according to Frank et al. (2019b) corresponds to the development stage of Industry 4.0-related services. The interface is often seen in the use of DT, the main one examined in this regard being the IoT (Rymaszewska et al., 2017; Zancul et al., 2016). Other main technologies include cloud applications, big data, and big data analyses (Frank et al., 2019a). Servitization and Industry 4.0 converge at this highest stage of development (Frank et al., 2019b; Gaiardelli et al., 2021). According to Frank et al. (2019b), an integrated servitization and digitalization strategy is able to create added value for the internal production processes of manufacturers' existing digital service offerings, expressed as cost reductions and increases in productivity and flexibility. Correspondingly, advocates of this perspective, Bortoluzzi et al. (2020), Frank et al. (2019b), Gaiardelli et al. (2021), argue that digital advances are taking place in both the product-service offering and manufacturers' production processes.

Literature linking DS and I4.0 is still rare. Most of the literature relates servitization to digital transformation in general or analyses the role of specific DT for servitization (Frank et al., 2019b). Other authors consider servitization as part of Industry 4.0 (Dalenogare et al., 2018; Frank et al., 2019a), and servitization and DS as a prerequisite, driver, or determinant for its adoption (Sony and Naik, 2020). Frank et al. (2019b) made the first valuable contribution linking DS with Industry 4.0, developing a conceptual framework for this purpose and stating that these are complementary concepts for two reasons. First, the disciplines of DS and Industry 4.0 are connected by their need for the same technologies and competences, namely the IoT, cloud services, big data, and analytics (Frank et al., 2019a, 2019b). This is supported by Lichtblau et al. (2015), who suggest that smart products and smart services should be able to interact with autonomous, self-regulated, and flexible internal Industry 4.0 production processes to maximize value (Sony and Naik, 2020). Second, I4.0-related services can and should be designed in such a way that they not only provide value to customers, which is the classical approach to (digital) services, but also so that customers can benefit from a firm's internal processes. This can be achieved by advanced digital services collecting and harnessing data on customers, their processes, and requirements, and also on the firm's own products and on-site performance. Knowledge can thereby be derived for internal manufacturing and engineering processes, allowing value-related improvements and gains such as cost reductions and increases in productivity, flexibility, and product quality (Frank et al., 2019b). Dalenogare et al. (2018) confirm that digital services help to obtain feedback on the firm's own products and manufacturing processes. We therefore argue for our second hypothesis:

H2. The higher the level of digital servitization, the higher a company's Industry 4.0 level.

To create the *hypotheses framework* of our study (see Fig. 2), we consider the three facets for the *level of digital servitization* separately, as described above: (a) the scope of digital service solutions, (b) the depth of digital service integration, and (c) the extent of the digital service portfolio. This allows more detailed analyses of the downstream-related (H1) and upstream-related hypotheses (H2). We test both hypotheses considering all three facets of DS. It is also important to consider the industrial context of the manufacturer to consider the underlying factors of technology adoption, process innovation, and digitalization, and to avoid misattributions. Regarding (digital) servitization capabilities, we follow previous studies that consider company size, sector affiliation, complexity of the manufactured product, and batch size, among others (Belvedere et al., 2013; Lay et al., 2010).

3. Data and methodology

To test these hypotheses, we conducted empirical research based on data from the *German Manufacturing Survey* (GMS) 2018, which is part of the wider European Manufacturing Survey (Fraunhofer Institute for Systems and Innovation Research ISI, 2024). It contains detailed information on servitization and digitalization in manufacturing firms, and the authors belong to the scientific team responsible for its operationalization and questionnaire development.

3.1. Data sample

The GMS is a survey of manufacturing firms in Germany conducted every three years by the Fraunhofer Institute for Systems and Innovation Research ISI. Since 1995, the objective of this survey is to systematically monitor manufacturing industries in Germany and their modernization trends. It addresses product, process, service, and organizational innovations. GMS data have been used in several firm-level research articles (Dachs et al., 2019; Horvat et al., 2019; Lay et al., 2010).

The survey addresses firms in Germany with 20 or more employees from all manufacturing sectors (NACE Rev. 2, 10–33). The initial sample was drawn as a proportionally stratified random sample according to the distribution in the population, considering firm size, region, and sector. Address information from the Hoppenstedt Group's firm database, which achieves relatively high coverage of the industry in Germany, served as the sampling frame (Jäger and Maloca, 2019).

Based on the size of the company, a different respondent was selected and personally asked to complete the questionnaire for their location. With the aim of addressing an informant who managed production at the highest level and therefore had organizational, technical, and strategic insights into the operation, we approached either the production manager, CTO, or CEO of the production site.

The survey took the form of a mixed-mode survey with a postal survey as the main approach. Respondents were also offered the option of completing the survey electronically on a PDF form (Sakshaug et al., 2019). For methodological rigor and following the multistep procedure for respondents receiving mailed invitations, they were reminded several times by different mailing methods (e.g. Bavdaž et al., 2020; Tuttle et al., 2018). The field period lasted a total of 4 months.

The random sample was processed according to a strict protocol. Of the eligible 17,305 firms contacted, a total of 1256 returned a useable questionnaire with at least two-thirds of the question blocks answered. This resulted in a return rate of 7.25 % of the adjusted net sample (Jäger and Maloca, 2019).

We can state that the data obtained were representative of the manufacturing industry in Germany as regards regional distribution, and size classes were in line with the distribution in the data from the Federal Statistical Office. The industry structure is also well represented, especially the core sectors, the only exception being a lower share of returns by food producers (Jäger and Maloca, 2019). Appendix 1 contains basic structural information about the data and includes respective numbers for sector and firm size provided by the Federal Statistical Office (Statistisches Bundesamt, 2019) for comparison. Applying the successive wave analysis to assess a potential non-response bias (e.g. Duszynski et al., 2022), a comparison of the firms that responded early in the survey period with those that responded later revealed no relevant differences in key indicators (Jäger and Maloca, 2019).

3.2. Variables and measures

We relied on measures of the usage of digital platforms and manufacturers' level of I4.0 as the variables to be explained to test our hypotheses. It was also necessary to operationalize the level of DS by manufacturers in its various dimensions as the explanatory factor of major interest. Table 1 provides an overview of the indicators used in

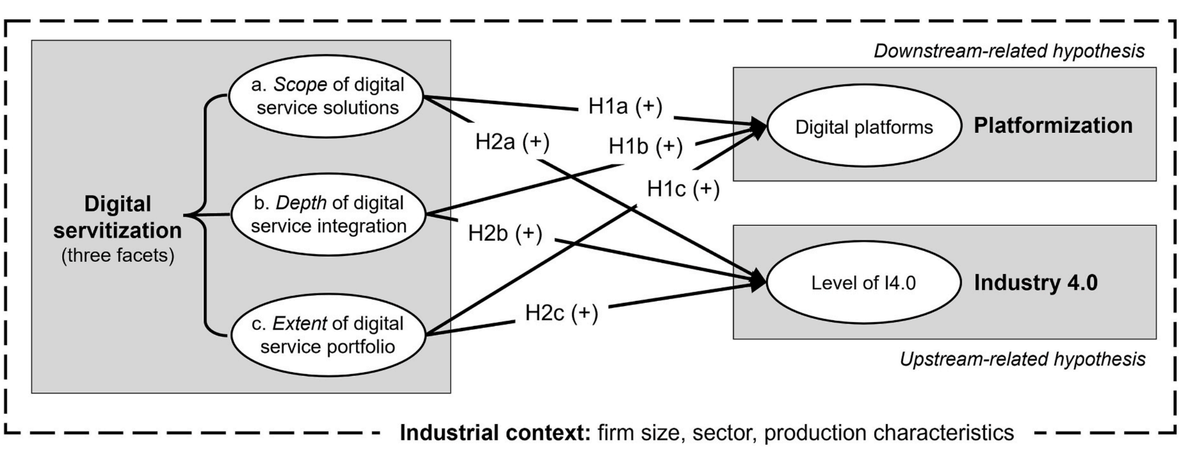

Fig. 2. Research hypothesis framework.

Table 1
Dependent variables and key indicators of the facets of digital servitization.

Construct		Definition	Type of variable
Dependent variables			
A)	Digital platform usage	Differentiates between firms (1) that use digital platforms and firms that (0) do not.	1 dummy
B)	I4.0 level	Differentiates between (1) beginners on the path towards I4.0, (2) advanced users, and (3) the top group, and (0) non-users as the reference group.	Index with 4 categories resp. 3 dummies
Facets of digital servitization			
C)	Scope of digital service solutions	# of digital service solutions offered, from 0 to 6	Count variable
D)	Depth of digital service integration	Differentiates between (1) digital service solutions supporting the product (SSP); (2) digital service solutions supporting the client (SSC), and (3) digital service solutions supporting the product and the client, considering service providers only (SSPC).	Nominal resp. 3 dummies
E)	Extent of digital service portfolio	Differentiates between (1) manual standard services; (2) manual advanced services; (3) digital standard services; (4) digital advanced services, and (0) no digital service offer	Ordinal resp. 5 dummies

our analysis.

3.2.1. Dependent constructs: digital platform usage, I4.0 level

First, firms were asked directly about the *use of digital platforms* (construct A) in the context of the services offered ("*Do you also offer product-*support *services through web-based platforms?*"), such that the indicator differentiates between firms offering services that use a digital platform and those that do not.

Second, to describe the technological *Industry 4.0 level* (construct B), we used the I4.0 readiness index presented and applied in Jäger and Lerch (2020) and Palčič et al. (2020), which depicts the degree of digital production in manufacturing companies. Following Lichtblau et al. (2015, p. 9), I4.0 readiness is understood *as* "the extent to which a firm has the necessary capabilities to (potentially) implement cyber-physical systems to create a smart factory by using corresponding technologies for communicating in real time along the value chain". The index is based on information provided by firms on their use of seven digital production technologies, which can be divided into three technology fields: *digital management systems, wireless human-machine communication, and cyber-physical systems (CPS)* (see Appendix 2). In order to differentiate between different I4.0 levels, the index not only tracks the number of DT used, but also considers the technological fields in which the firms are active in and whether they use and combine several fields at the same time (see Appendix 3). This approach makes it possible to capture the various stages of production digitalization on the path to I4.0.

3.2.2. Explanatory factor: level of digital servitization

DS is operationalized using three indicators to represent separately the three facets of the level of DS (Table 1). These are the *scope of digital service solutions* (construct C), the *depth of digital service integration* (construct D), and the *extent of the digital service portfolio* (construct E). These indicators allow the diffusion of digital services and the development of DS in the manufacturing sector to be assessed in all their diversity, also facilitating a more detailed description of DS among service providers and digital service providers. Moreover, it allows the impact on the spread of digital platform usage and the spread of Industry 4.0 technologies to be analyzed in greater detail. In this regard, each hypothesis was tested three times, allowing each facet to be analyzed separately.

First, the *scope of digital service solutions* (construct C) was captured by the number of digital service solutions a firm offered. The indicator ranged from 0 for companies with no digital solution in their service portfolio, to 6 for companies offering all five specific digital solutions, plus at least one other digital service solution. This indicator counts how many of the given types of digital service solutions are offered by the companies as part of their service portfolio. Five types of digital service solutions were provided to choose from (see Appendix 4). Another digital solution for services could also be added as an open entry. By counting the number of digital service solutions offered, the indicator shows the extent to which the service offering is implemented or supported by digital service solutions.

Second, we focused on the *depth of digital service integration* (construct D) to explore whether the digital tools were designed to enhance the overall customer experience, or if they were primarily no more than services linked to the product. In this regard, we drew on the concept of differentiating the service offering according to the type of recipient (Kowalkowski et al., 2013; Mathieu, 2001) transferring this approach to digital service solutions. To do so, we divided the digital service solutions listed in Appendix 4 into two categories based on the recipient of the digital service solution, allowing us to distinguish three groups, as indicated in Table 1, each characterized by an increasing depth of integration of digital services.

The third indicator captured the *extent of the digital service portfolio* (construct E). It combines the differentiation between manual and digital services (Frank et al., 2019a), and the distinction between standard services (as a combination of basic and intermediate services) and advanced services (Baines and Lightfoot, 2014). To construct this indicator, we used information about whether a company offers certain services. The GMS 2018 data allowed us to identify whether a company offered at least one of eight standard services or at least one of five advanced services. Appendix 5 gives an overview of all the kinds of services considered. In combination with information on whether services were provided digitally by using digital service solutions (see Appendix 4), four groups of manufacturing firms that offer (digital) services could be distinguished. The group of non-service providers remains the reference group for this classification (see Table 1 and Appendix 6).

These three indicators are not statistically independent but rather describe the three facets of DS, i.e., they describe DS from different perspectives and with different foci. The constructs are neither independent nor strongly correlated when focusing on digital services only (Appendix 7).

3.2.3. Further independent variables: controlling the context of the manufacturing firm

The GMS 2018 also provides information about the context of the manufacturing firm. As is common in studies on the manufacturing industry, we controlled for sectoral affiliation, distinguishing manufacturers of different products according to the statistical classification of economic activities NACE, revision 2. Furthermore, company size can be used in analyses based on the number of employees, reflecting organizational complexity, financial capabilities, and organizational possibilities in terms of administration and legal consultation. The GMS data also allow the consideration of product complexity and batch size, which have a considerable impact on both servitization and digital capabilities, and the behavior of the manufacturer (e.g. Lay et al., 2010). The production of similar goods in large batches is less closely linked to individual customers, so additional services are less likely to be offered (Lay et al., 2010). Producing complex products may lead to closer interaction with clients, providing more opportunities to offer specific services around the product. These variables, their measurement levels, and their classifications can be found in Appendix 8.

3.3. Model description

First, we described the central constructs and their relationships using univariate and bivariate analyses. Since the data are fairly representative of the population, these analyses provide an initial insight into DS in German manufacturing. Moreover, the correlation to I4.0 level and platform utilization can be uncovered and statistically tested. In a second step, the hypotheses on the relationship between DS and digital platforms, and between DS and I4.0-level, were tested using multiple regression models. For each dependent construct, the effects of the three facets of DS were tested separately and independently of each other. All regression analyses were estimated considering the relevant factors of company size, industry affiliation, product complexity, and batch size.

These three facets reflect different perspectives on DS but are not necessarily entirely (statistically) independent (Appendix 7), so the separate estimations allowed us to assess the size and direction of the impact and to compare its explanatory power. Notably, the impact of the scope and extent of DS could be analyzed including all manufacturers (ñ1200). The effect of the depth of digital service integration is nominal in nature and exclusively differentiates firms that use digital service solutions. Therefore, these models were restricted to these firms only (ñ400).

We selected the type of regression model according to the dependent constructs. Standard logistic models were estimated for the *digital platform* indicator due to the binary nature of the indicator. To this effect, the results represent the estimation of the influences of all considered factors on the use of digital platforms.

Moreover, the models of the different *I4.0 levels* were calculated as logistic regressions. This decision was based on the consideration that as an indicator of ordinal value, we could not use a linear regression model to analyze I4.0 level. Furthermore, when running the ordinal regression models, the basic proportional odds assumptions were not met for all the independent variables. Additionally, the test for empty cells did not match the requirements because of the inclusion of several independent factors. This also limits the application of multinomial regression model estimations (e.g. Long and Freese, 2014). Consequently, we decided to test the relationship between DS and the I4.0 levels separately for the different thresholds between the levels and are therefore estimating separate logistic models for each.

The *first model* estimates the odds of being among the non-users and all other firms. The *second model* differentiates between the group of non-users and beginners, and between the group of advanced users and firms in the top group. The *third model* estimates whether a firm belonged to the top group or not. The results showed the extent to which DS played a role at the specific level of I4.0, enabling conclusions to be drawn about the three facets of DS. The sequences of the three logistic regressions were interpreted separately and in comparison.

Both ordinal regression models and multinominal regressions were calculated to revise the estimated results. For documentation purposes, the estimated results for H2a based on a multinomial regression model were added to Appendix 14. All other regressions estimated for the purpose of testing the results can be made available upon request from the authors.

4. Results

4.1. Results from the descriptive and bivariate analysis

The descriptive data on the level of (digital) servitization in the German manufacturing sector in 2018 are summarized in Appendix 9, and the descriptive data on both dependent variables in Appendix 10. The indicator for the extent of the digital service portfolio shows that although 87 % of all manufacturers offered services, only 35 % had digital service offerings. Consequently, while servitization was already very widespread, the level of DS was still rather low. Moreover, around half of all manufacturers that used digital service solutions had just a single digital solution in place (17 %), which also suggests a low level of digitalization in the services offered. The results of the companies' usage of digital platforms and I4.0 level also reveal a low diffusion rate of digital processes and business relations at the time the survey was carried out. Only 16 % of all manufacturers applied digital platforms to provide their service offerings. Furthermore, more than two-thirds of all manufacturers were either non-users (14 %) or beginners in I4.0 (54 %). Accordingly, only one third of all firms belonged to the advanced users (25 %) or the top group (8 %).

The graphs in Fig. 3 show the correlations between the level of DS and the use of digital platforms (H1). As the top graph indicates, the use of digital platforms differs statistically significantly between firms with no digital service solutions and those with one, two, and three or more digital service solutions.

Consequently, the more digital service solutions used, the more likely the use of digital platforms (H1a). Notably, manufacturers that provide digital service solutions to support the client (SSC) or both recipients (SSPC) use digital platforms much more frequently than firms that only use their digital service solutions to support their products (SSP) (H1b).

Regarding the extent of the digital service portfolio, the firms offering digital services showed significantly higher shares of digital platforms than the other groups. Consequently, the use of digital

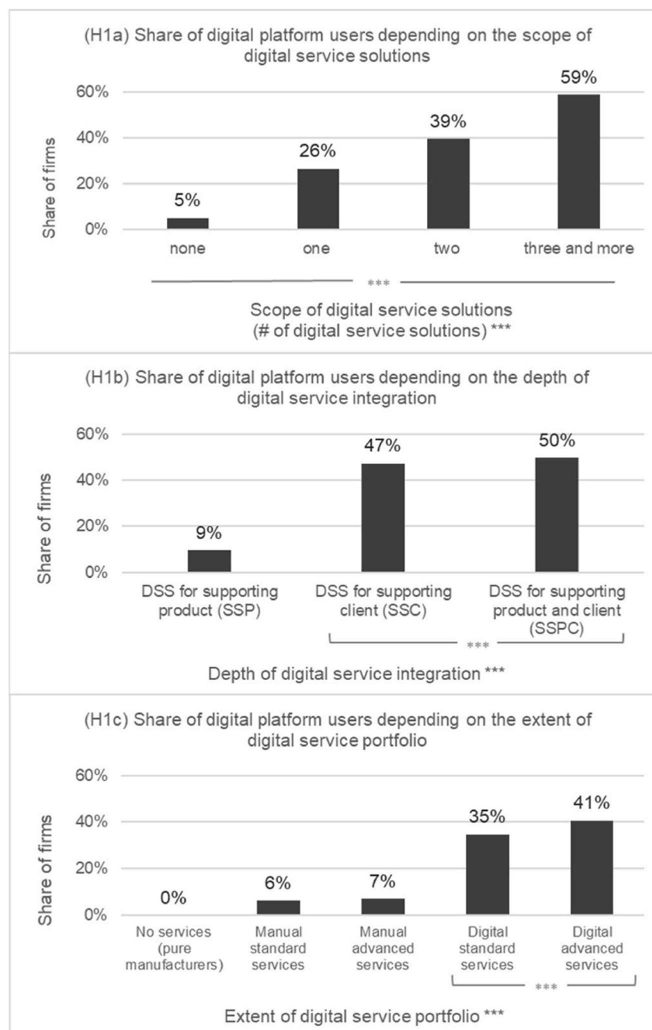

Fig. 3. Share of digital platform users depending on the level of digital servitization (H1)

Note: Significance level: *p < 0.1; **p < 0.05; ***p < 0.001.

Source: *German Manufacturing Survey* 2018, own calculations.

platforms differs crucially depending on the offer of digital services as opposed to manual services, regardless of whether they are standard or advanced services (H1c).

To show the relationship between DS and the I4.0 level, Fig. 4 contains the share of advanced users and the top group: he share of the two I4.0 groups together is highest among manufacturers that use two, three or more digital service solutions (H2a). Moreover, 15 % of the firms that use SSC belong to the top group, while 24 % of these firms are in the group of advanced users. However, firms that use SSP are also likely to be in the group of advanced users (31 %), although they are rarely in the top group (3 %). Only if firms combine their digital service solutions for SSPC is the share of the two I4.0 groups presented statistically significantly above average (H2b). Regarding the extent of the digital service portfolio, only the providers of digital services achieve a statistically significant above-average share of higher I4.0 levels. Providers of manual advanced services achieve average shares of higher I4.0 levels. The two lowest groups in the extent of digital service portfolios show no differences in the I4.0 level and are below average overall (H2c).

4.2. Results of the multiple regression analyses

We conducted multiple regression analyses to test H1 and H2. A summary of the estimations is shown in Table 2. Appendix 11 and

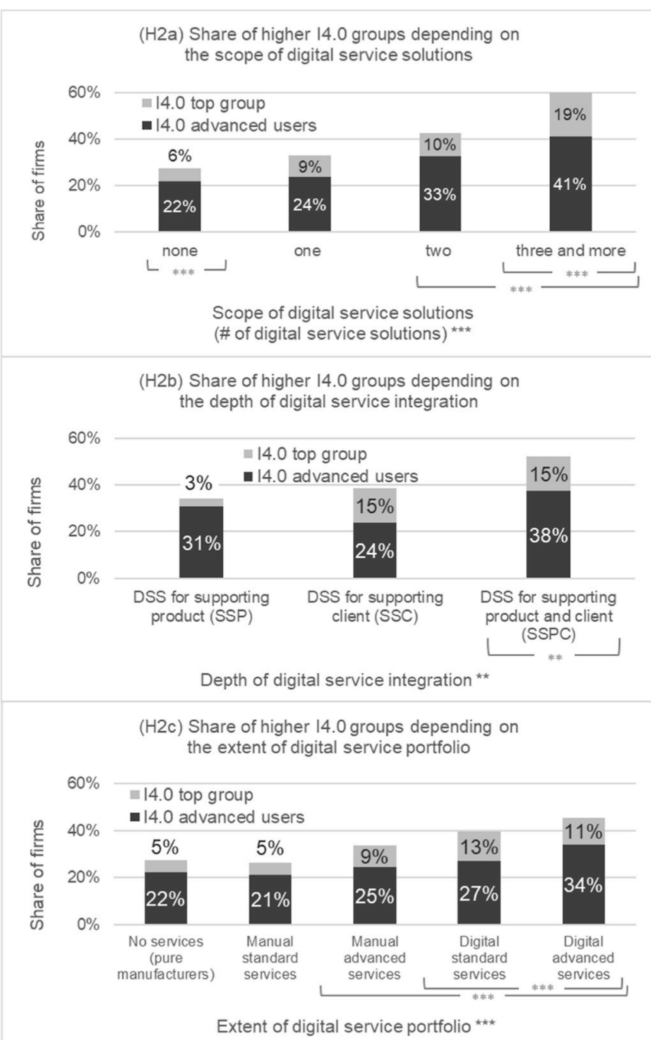

Fig. 4. I4.0 level depending on the level of digital servitization (H2)
Note: Significance level: *p < 0.1; **p < 0.05; ***p < 0.001.
Source: *German Manufacturing Survey* 2018, own calculations.

Table 2
Impact of the level of digital servitization (H1 and H2).

dependent variable	Hypothesis 1		Hypothesis 2					
	digital platforms		I4.0 level: non-users		I4.0 level: advanced users/top group		I4.0 level: top group	
	(a)		(b)		(c)		(d)	
	OR	*sig.*	*OR*	*sig.*	*OR*	*sig.*	*OR*	*sig.*
(A) Scope of digital service solutions	***		**		**		n.s.	
one DSS (1)	6,9	***	0,4	**	1,1	n.s.	1,4	n.s.
two DSS (1)	13,8	***	0,4	**	1,6	*	1,3	n.s.
three and more DSS (1)	33,8	***	0,5	n.s.	2,8	***	2,6	**
(B) Depth of digital service integration	***		n.s.		n.s.		*	
DSS for supporting product (SSP) (2)	0,1	***	1,0	n.s.	0,6	n.s.	0,3	**
DSS for supporting client (SSC) (2)	1,0	n.s.	0,8	n.s.	0,6	*	0,8	n.s.
(C) Extent of digital service portfolio	***		**		**		n.s.	
Manual standard services (3)	–		0,9	n.s.	0,9	n.s.	0,9	n.s.
Manual advanced services (3)	2,0	*	0,6	n.s.	1,3	n.s.	1,6	n.s.
Digital standard services (3)	10,3	***	0,3	**	1,3	n.s.	1,5	n.s.
Digital advanced services (3)	16,1	***	0,4	**	1,7	*	1,9	n.s.

Notes: Significance level: *p < 0.1; **p < 0.05; ***p < 0.001. Logistic models on manufacturing firms with reference to (a) Firms not using digital platforms for services, (b) Firms using digital technologies in production (I4.0 level above 0), (c) Firms using no digital technology in production or only in one or two fields (I4.0 level below 2), (c) Firms having not reached the I4.0 top level. Models are controlled by firm size, sector affiliation, product complexity, and batch size. Models (A) and (C) include manufacturing firms, model (B) includes manufacturing firms with digital service solutions only. See Appendix for more details.
Reference groups for independent indicators: (1) no digital support techniques used. (2) DSS supporting product and client (SSPC). (3) no service offer (or only standard manual services).
Source: *German Manufacturing Survey* 2018, own calculations.

Appendix 12 summarize the statistical significance level of all other constructs for H1 and H2, respectively. Appendix 13 contains details of models on the impact of the indicator *scope of digital service solutions* (H1a and H2a).

First, as the numbers in Table 2 clearly indicate, H1 can be upheld. For all three facets of DS, the relevant indicators show a statistically significant impact on a firm's usage of digital platforms (column A). We can state that the higher the level of DS, the more likely a manufacturer is to use digital platforms. Regarding the *scope of digital service solutions* (H1a), the estimates indicate that firms with three or more digital service solutions are 34 times more likely to use a digital platform than firms with no digital solutions. Even firms providing just one digital solution are seven times more likely to use such a platform. The *depth of digital service integration* is also a relevant predictor of the usage of digital platforms (H1b). The estimations show that firms that offer digital service solutions to support just the product are less likely to use digital platforms than firms that offer digital service solutions to support the client. Last, regarding the *extent of the digital service portfolio* (H1c), we can state that firms with a more digitally advanced service portfolio are more likely to use digital platforms. Meanwhile, firms offering advanced digital services are 16 times more likely to use these platforms than manufacturers with no service offering or only manual standard services. Furthermore, firms offering standard digital services are 10 times more likely to use them. All these results are statistically significant, even when controlling for firm context.

Besides this relationship, the models reveal that the likelihood of using a digital platform is determined by firm size and is related to some extent to the industrial sector a firm belongs to (see Appendix 11). Larger firms tend to use these digital platforms more frequently than smaller ones. Companies in processing industries such as the food, beverage and tobacco industry, and the chemical industry are more likely to use these platforms than firms in the reference metal and metal products industries. Production characteristics have no additional explanatory power. In conclusion, the diffusion of digital platforms seems to be mainly dependent on a firm's resources, the level of DS, and market opportunities in the sectors, while it is less influenced by product complexity and batch size.

Second, to test H2 we explored the relationship between the level of DS and the I4.0 level (Table 2, column b to d). The step between each I4.0 level is displayed separately, and an overall assessment of the relationship is made by combining the results. We can state that the results for the three facets of DS differ significantly. First, a statistically robust influence of the *scope of digital service solutions* (H2a) and the *extent of the digital service portfolio* (H2c) on the differentiation between a lower and higher I4.0 level was estimated (columns b and c). The *depth of digital service integration* does not seem to be relevant for this differentiation (H2b). Only for the differentiation between the top group and the other firms was a statistically measurable correlation found when all other factors were controlled (column d).

On studying the *scope of digital service solutions* (H2a) in greater detail, we found that firms with one or two digital service solutions were statistically less likely to be in the group of I4.0 non-users. Meanwhile, firms with two digital service solutions were 1.6 times more likely to show a higher level of I4.0, and firms with three or more digital service solutions were nearly three times more likely to be in this group than firms with no digital support. Furthermore, the likelihood of being in the top group was higher for the firms with three or more digital service solutions. Considering the *scope of digital service solutions*, the level of DS is linked to the level of I4.0 of manufacturers, so H2a is upheld.

Regarding the *extent of the digital service portfolio* (H2c), we identified that companies offering either standard or digital advanced services were statistically less likely to be in the group of I4.0 non-users. Furthermore, firms offering digital advanced services were more likely to be in one or both higher I4.0 groups, although the results are only statistically significant at the 10 % level. Moreover, the difference between being part of the top group and only reaching a lower I4.0 level does not depend on the *extent of the digital service portfolio*. These results suggest that the difference between firms not using digital technologies and firms with higher I4.0 levels is clearly linked to the *extent of the digital service portfolio*. However, this relation is not found when examining differences at the higher I4.0 levels (column d). To this effect, there is no support for H2c because the DS level of a manufacturer is not positively linked to the I4.0 level of a company at every possible level.

Last, there is no support for H2b. As stated above, the *depth of digital service integration* is not positively linked to the I4.0 level of a company. However, and interestingly, the analysis shows that firms that focus on offering SSP rather than SSC are more likely to be in the I4.0 top group. Appendix 12 provides additional insights into the major influencing factors on the I4.0 level. In all models, it is estimated that firm size has a statistically significant impact in this regard. The larger the firm, the greater the likelihood of reaching a moderate or high I4.0 level. Moreover, firms producing low and medium complex products show on average a lower I4.0 level than those producing complex products. The production batch size also influences the manufacturer's I4.0 level. On average, firms with single unit production tend to have a lower I4.0 level than manufacturers with large-scale production. However, whether a company is a beginner or is in the top group is not determined by the batch size of production. Sectoral affiliation generally has nearly no impact on the I4.0 level once the degree of digital servitization is controlled. Only in the model that utilizes the *scope of digital service solutions* does the sectoral affiliation determine the I4.0 level to a certain extent.

The robustness check, carried out by estimating the models using ordinal regression and multinomial regression models, revealed comparable results. As an example, Appendix 14 contains the detailed results of the multinomial regression model calculated as a robustness test for H2a. The impact of production characteristics as context information is even more prominent. Moreover, the impact of both relevant dimensions of the level of DS was supported.

5. Discussion

We identified two effects that occur because of establishing DS capabilities and transferring them within a manufacturer's value creation sphere. The first effect concerns the influence of digital services on digital platforms (downstream-related hypothesis), and the second the impact on Industry 4.0 (upstream-related hypothesis). Given this background, we formulated our research question as, *'What is the impact of digital servitization on the use of digital platforms and Industry 4.0 among manufacturing firms?'*. To answer this question, we used a representative, large-scale firm-level data set, and we conducted descriptive, bivariate, and multiple regression analyses.

5.1. The role of the facets of digital servitization

In general, our analyses showed that manufacturers' digital service offerings have a positive influence on both the use of digital platforms and the I4.0 level. Moreover, we can state that the higher the level of DS, the higher the likelihood that Industry 4.0 and platforms will be used simultaneously. These findings are generally in line with earlier research (Eloranta et al., 2021; Frank et al., 2019b; Gebauer et al., 2021; Rapaccini et al., 2023; Tian et al., 2022).

Moreover, our study provides detailed insights into the mechanisms that describe the impact of the level of DS on platformization and I4.0. To this effect, we considered three facets of DS: the (a) *scope of digital service solutions*, the (b) *depth of digital service integration,* and the (c) *extent of the digital service portfolio*. Overall, the three facets unfold different impacts and at the same time highlight the required DS capabilities that drive digital platforms and I4.0.

Regarding a manufacturer's DS capabilities (Lenka et al., 2017; Münch et al., 2022), we propose that to boost the impact on platformization, a company must offer at least digital standard services or services supporting the client (SSC) in their business activities (see H1b/c). In this case, it is significantly more likely that the manufacturer will have capabilities to link its digital platform with its service offerings. This result confirms the findings of previous qualitative papers on the digital journey of manufacturers. Rapaccini et al. (2023) show that firms initially sell basic services with the help of the digital platform after a pilot phase, while Lerch et al. (2024) find that in the early phases of a manufacturer's platform business, services that support and integrate the customer are particularly offered. Furthermore, the more digital solutions used, the more a manufacturer will interlink its digital platform to service offerings (H1a). The importance of digital connectivity to leverage platforms has been emphasized in a prior work by Eloranta and Turunen (2016), and is manifested in the number of digital solutions used.

In contrast, I4.0 is only triggered when the manufacturer offers digital advanced services or services that not only support the client but also the product (see H2b/c). With this result, we not only expand the perspective of the DS journey (Rapaccini et al., 2023) in terms of an upstream expansion of the value co-creation sphere, but we also show the conditions for the convergence of servitization and I4.0 (Frank et al., 2019b). In practice, this situation occurs as soon as the manufacturer has the capability to implement I4.0 applications and does so simultaneously, both in its own production and at the customer's site. Moreover, the more digital service solutions used, the more a manufacturer is oriented towards I4.0-related services (H2a).

5.2. Context of the early stage of digital servitization: early birds and multi-adopters

Our paper relates to the year 2018 and to Germany, and therefore refers to an early stage of DS in that country. This is confirmed by the fact that although 9 out of ten manufacturers (87 %) were active in servitization at that time, only a third of all firms had digital service offerings. Similarly, the use of digital platforms (16 %) and I4.0 technologies (33 % of advanced and top users) was not widespread among companies. This shows that despite a low level of digitalization in manufacturing, the phenomena of platform-based servitization and I4.0-related services had already occurred. In this context, we can state that the earlier qualitative case study analyses dealing with this topic (Frank et al., 2019b; Lerch et al., 2024; Rapaccini et al., 2023; Tian et al., 2022) do not describe just special cases of digital pioneers or large-sized established manufacturers. Rather, our quantitative results show that these correlations can be found across the entire German manufacturing sector, thereby applying to a significant share of firms. Although the group of manufacturers with DS was comparatively small at this early stage, our results indicate that as soon as companies started offering digital services they reasonably quickly switched to platform-based servitization or to I4.0-related services.

Our results allow conclusions to be drawn about the type of firms that have adopted DT in multiple spheres at this early stage. Two aspects are relevant here: first, we can state that the size of the firm is a decisive criterion for becoming a "multi-adopter". The larger the company, the greater the likelihood that digital service offerings, digital platforms, and I4.0 applications will be used simultaneously. This can be attributed to the fact that large companies can build up capabilities more easily than smaller firms due to their increased resources (Münch et al., 2022; Raddats et al., 2015). Moreover, larger companies tend to have more advanced learning processes for receiving, processing, and storing information (Crossan et al., 1999; Momeni et al., 2023).

Second, we can conclude that the "early birds" of DS were particularly likely to transfer their digital capabilities to other parts of their own value creation sphere. Our analyses showed that in 2018, manufacturers with highly digital, advanced, and customer-centric service offerings were also the most likely to have a high level of I4.0 and digital platforms simultaneously. This "early bird" effect goes hand in hand with the chosen case studies in previous works (Frank et al., 2019b; Lerch et al., 2024; Rapaccini et al., 2023; Tian et al., 2022). Consequently, the stronger the DS capabilities, the more likely companies are to become multi-adopters. This means that companies at the forefront of a technological trend generally appear to be better able to use their learning effects to establish, transfer, and apply new capabilities inside their company.

Beyond firm size and the level of DS capabilities, our multivariate analyses also show that the industrial context of a company is crucial. We can confirm that the structural factors from previous quantitative studies, such as Dachs et al. (2013), Lay et al. (2010), Marques et al. (2015), are also relevant for our subject of investigation. However, regarding the impact on platformization and the I4.0 level, we can provide a new context: In the case of digital platforms, it is not only the level of DS that plays a role, but also the firm sector. Manufacturers from the process industries, such as the food, beverage and tobacco industry, and the chemical industry, are more likely to be able to link digital platforms with suitable service offerings than companies from other sectors. In conclusion, platform-based servitization (Tian et al., 2022) seems to be mainly dependent on a firm's level of DS and on market opportunities in their sectors. In contrast, the I4.0 level of a manufacturer is not dependent on the sector. In this case, aside from the level of DS, the production characteristics of a manufacturer play a decisive role. The more complex the product or the larger the batch size, the more likely manufacturers are to be able to link digital services with I4.0 applications. The phenomenon of I4.0-related services (Frank et al., 2019b) is therefore likely to be particularly prevalent among manufacturers with complex products or large-scale production. Overall, we can therefore conclude that platform-based servitization is more market-driven, while I4.0-related services are more production-driven.

5.3. Impact on the value co-creation sphere

As Lenka et al. (2017) found, the value co-creation sphere can be expanded through digital capabilities in servitized firms. Our analyses mean we can now determine the impact of DS on the value co-creation sphere in detail. In this context, we can conclude that each single facet of DS provides information on whether expansion happens upstream or downstream.

The first facet, 'scope of digital service solutions', has an equal impact on upstream and downstream expansion. This is because each additional service solution increases the likelihood of a manufacturer using digital platforms and increasing the I4.0 level simultaneously (see H1a/H2a). We therefore assume that with each additional digital technology, the value co-creation sphere between provider and customer can be expanded in both directions, and process integration can also be intensified. Regarding the second facet, 'depth of digital service integration', we must differentiate by the recipient. As H2a and H2b show, each step of deeper integration has a distinct effect on the joint sphere. In the case of SSC, a downstream expansion can be inferred, whereas if the manufacturer offers SSPC, there is both an upstream and a downstream expansion. SSP do not affect the sphere. For the third facet, 'extent of the digital service offering', we can see that manual services have no effect on the sphere. In this regard, expansion only takes place from a digital service offering (see H3a/H3b). Manufacturers that offer digital standard services tend to expand the joint sphere downstream. When offering digital advanced services, however, there is both an upstream and a downstream expansion of the value co-creation sphere.

Consequently, for the second and third facets, we can conclude that an upstream expansion requires higher DS capabilities than a downstream expansion. In practice, this means that upstream expansion is mostly coupled with downstream expansion, whereas downstream expansion also often takes place independently. In other words, a servitized firm will first move to platform-based servitization before building up I4.0-related services as the required capabilities are easier to establish. Beyond DS capabilities, the provider and customer context plays a role in the expansion of the joint sphere. While downstream expansion is sector-specific and favors companies from the process industries (platform-based servitization), upstream expansion is particularly triggered by complex products and large batch sizes (I4.0-related services).

6. Conclusions

Understanding whether DS is a driver for digital platforms and Industry 4.0 is essential for companies in the digital age. In terms of technology adoption and implementation (Gradillas and Thomas, 2023) during a firm's digital transformation, digitalization is a complex and sinuous process resulting in transformed business processes and applications. Our research provides an enhanced understanding of this phenomenon as well as empirical evidence for the manufacturing-wide generalization of the various facets of DS as drivers for platformization and I4.0. Our work contributes to the current literature by expanding knowledge about strategies and practices during manufacturers' digital transformation.

6.1. Academic and theoretical contributions

Our study makes some theoretical contributions to current research on DS. It initially contributes to *three respective literature streams*. The literature on the servitization platform approach analyzes, among other aspects, how platform-based business models can be offered (Haaker et al., 2021; Tian et al., 2022), how inter-organizational relationships can be managed (Eloranta and Turunen, 2016), and how value can be leveraged from digitalization with the help of servitization (Cenamor et al., 2017). However, it is still unclear what specific conditions are necessary in practice to link digital service offerings with platforms. The situation is similar in the literature dealing with the relationship between I4.0 and servitization, which generally designs conceptual models and frameworks based on case studies or uses theories for this purpose (Ennis et al., 2020; Frank et al., 2019b). Furthermore, ideal-typical business models are identified (Paiola et al., 2021) and servitization strategies are considered (Bortoluzzi et al., 2020). Ultimately, for both literature streams we show the DT frequently combined in companies, thereby leading to the convergence of three digital transformations (Fang and Liu, 2024; Soellner et al., 2024; Zhao and Gao, 2024): DS, platformization, and Industry 4.0. The contribution to the third literature stream, technology management, which is currently strongly based on DT (Blichfeldt and Faullant, 2021; Kinkel et al., 2022; Rupp et al., 2021), lies in the findings on the interplay between servitization and DT. By considering the three facets, we go beyond a one-dimensional view of DS and add further determinants such as product characteristics (complexity), production configuration (batch size), company characteristics (size), and industry (field of activity). We analyze a broad set of factors that favor the adoption of DT, thereby expanding on earlier findings, such as those published by Narula et al. (2020). It is also relevant to consider the adopters. Working with a taxonomy of different technology adopters classified into different groups is a valuable contribution, providing a nuanced understanding of how different adopter groups interact with DT.

Moreover, we contribute from a *theoretical perspective* to explaining the mechanisms of organizational learning in the context of DS. Although multiple theoretical perspectives are necessary to fully understand the cultural change in servitization, organizational learning can be considered as the process of changing organizational values and procedures through the modification of structures and mental models to improve performance (Biesinger et al., 2024, p. 365). This description fully aligns with the transformation from a product-centric offering to platform-based servitization and I4.0-related services. Our findings also reveal the mechanisms of organizational learning wherein DS as a capability simultaneously pursues platformization and Industry 4.0.

Further academic contributions are the paper's *methodological and conceptual approaches*, thereby filling a gap in the servitization research. As the literature shows, most research on DS consists of qualitative works, case study analyses, and conceptual approaches (Paschou et al., 2020; Shen et al., 2023), with just a few papers using quantitative research in the DS stream or providing empirical evidence from large-scale surveys at firm level (Belvedere et al., 2013). Therefore, our methodological approach enabled us to not only statistically confirm the findings already obtained from the qualitative work, but also to complement and refine them.

6.2. Practical implications

For practitioners, we can derive two fundamental recommendations. First, the mechanisms of organizational learning, which may lead to the simultaneous development of digital capabilities in various spheres of the company, can be consciously used as part of a digital strategy. In practice, this means that while companies are undergoing digital transformation, service offerings, platforms, and their own production processes should be addressed holistically. Therefore, an end-to-end digital ecosystem should be established that connects the company's own production with its customers and product service offerings. This allows the acquired capabilities to be bundled in a targeted manner and disseminated to the various spheres of the firm, which supports the organizational learning mechanisms. This leads not only to synergy effects in the development of capabilities, but also to resource savings.

Second, regarding the development of digital capabilities, we can distinguish between two stages on the DS journey. (1) When entering the digital service business, manufacturers should ensure that they do not use digital solutions in isolated cases, but across the board. Moreover, the first digital services should be integrated at an early stage via platforms. This not only makes it more efficient to offer and distribute services, but it also improves the manufacturers' platform capabilities. In practice, this means that companies should start offering SSC, and therefore couple the platforms with, for example, product configurators, online training, automated error descriptions, and Big Data analyses. (2) When expanding the digital service business, manufacturers are advised to simultaneously move towards digital advanced services and Industry 4.0. Our analysis shows that both require similar capabilities, which should then be used across the entire value creation sphere. Digital integration and the development of the corresponding ecosystem can then take place via the already established digital platform. Here, the technology spectrum can be expanded to include, for example, monitoring systems, cyber-physical systems, and human-machine communication.

6.3. Limitations and future research

Like all research, our analysis has some limitations. First, it was not possible to clarify whether digital platforms or I4.0 tend to follow digital service offerings, or vice versa. The question as to whether DS is subject to a push or pull effect therefore remains open. Moreover, it is also conceivable that digital services, digital platforms, and I4.0 are introduced at the same time, so there is a simultaneous linkage. A topic for future research should be a time analysis to answer this question. Furthermore, we only considered the relationship between manufacturer and customer and examined the impact of DS capabilities on their joint sphere. However, PSS are often developed in ecosystems, which is why other players beyond the manufacturer and customer also build up these capabilities. Future work could therefore examine the development and impact of DS capabilities of multiple partners within ecosystems.

Second, our results are based on a large-scale survey and multiple regression analysis. Although this allowed us to identify reliable correlations, we cannot make statements about the digital strategies of single companies and their interplay in the development of digital capabilities. Our paper therefore confirms the need for further case study research in the context of DS journeys. More research is required to identify success factors and challenges to develop a deeper understanding of DS capabilities and their impact on the value creation sphere. Better recommendations for firms entering DS and moving towards platformization and Industry 4.0 can then be derived.

Third, our study only relates to the German manufacturing sector and refers to an early stage of DS. Although the results allow valid statements to be made for Germany, they should not be transferred directly to other countries. Furthermore, the correlations observed in this early stage should not be applied to later stages. In this regard, future research is needed on the interplay between DS, platformization, and the level of Industry 4.0 in other countries as well as for other stages. For example, it would be interesting to conduct this kind of analysis not only for industrialized countries in an early stage, but also for emerging or developing ones in later stages. This would show which country-specific or stage-specific effects interfere with the observed relationships identified for Germany in 2018.

CRediT authorship contribution statement

Christian M. Lerch: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Conceptualization. **Angela Jäger:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Andrea Bikfalvi:** Writing – review & editing, Visualization, Validation, Supervision, Methodology. **Cornelius Moll:** Writing – original draft, Investigation, Conceptualization.

Declaration of conflict of interest

The authors hereby confirm that there is no conflict of interest for our research paper *"Unpacking digital servitization: How its facets drive platformization and Industry 4.0"*.

Appendix 1. Basic descriptives for GMS and comparatively for the population

# of firms	n = 1.256 [(a)]	N = 45.815 [(b)]
Firm size (# of employees)		
up to 49 employees	47 %	49 %
50 to 99 employees	24 %	22 %
100 to 499 employees	24 %	25 %
500 and more employees	5 %	4 %
Sector (Nace rev. 2)		
Metal industry (24–25)	22 %	20 %
Machinery and automative (28)	17 %	14 %
Rubber and plastics; glass and stone products (22–23)	15 %	14 %
Electrical and electronic products (26–27)	12 %	9 %
Food and beverages (10–12)	9 %	13 %
Chemicals and pharmaceuticals (20–21)	4 %	4 %
Automotive and transport equipment (29–30)	4 %	4 %
Other sectors	17 %	21 %
Batch size		–
single lot manufacturing	26 %	
small/medium lot manufacturing	57 %	
big lot manufacturing	17 %	
Product complexity		–
simple products	21 %	
medium complex products	49 %	
complex products	30 %	

Sources: (a) *German Manufacturing Survey* 2018, Fraunhofer ISI. (b) Statistisches Bundesamt (2019). Own calculations.

Appendix 2. Technological base of I4.0 levels

Question stimulus: Which of the following technologies are currently used in your factory?
Technology field *digital management systems*
• software for production planning and scheduling (e.g., ERP system)
• product lifecycle management systems (PLM) or product/process data management.
Technology field *wireless human-machine communication*
• digital solutions to provide drawings, work schedules, or work instructions directly on the shop floor
• mobile/wireless devices for programming and controlling facilities and machinery (e.g., tablets).
Technology field *cyber-physical systems (CPS)*
• systems for automation and management of internal logistics (e.g., warehouse management systems, RFID)
• near real-time production control system (e.g., systems of centralised operation and machine data acquisition, MES)
• digital exchange of product/process data with suppliers/customers (electronic data interchange EDI)

Source: Own representation.

Appendix 3. I4.0 levels – definition of groups

Groups	Description of the levels
I4.0 non-users	firms do not use any of the DT studied.
I4.0 beginners	firms use at least one digital technology in one or two technology fields, it indicates a low level
I4.0 advanced users	firms are active in all three technological fields and use one or two CPS-related technologies in production, which indicates a moderate level
I4.0 top group	firms are active in all technology fields and use all three CPS-related technologies, it captures the pioneers on the path towards I4.0 and is the highest level

Source: Own representation.

Appendix 4. Digital service solutions and their domains

Question stimulus: Which of the following digital solutions do you offer as part of your service portfolio?
*Digital service solutions for supporting the product (**SSP**) by using*
• mobile devices for diagnosis, repair, or consultancy (e.g., digital camera, smartphone, tablets etc.)
• digital (remote) monitoring of operating status (e.g., condition monitoring)
*Digital service solutions for supporting the client (**SSC**) by offering*
• web-based offers for product utilization (online training, documentation, error description)
• web-based services for customized product configuration or product design
• data-based services using big data analysis

Source: Own representation.

Appendix 5. Service offerings considered and their classification

Standard services
Question stimulus: Which of the following product-related services do you offer your customers?
• Installation, start-up
• Maintenance and repair
• Training
• Remote support for clients
• Design, consulting, project planning
• Software development
• Revamping or modernization, and
• Take-back services (e.g., recycling, disposal, taking back)
Advanced services
Question stimulus: Which of the following business models do you offer your customers?
• Renting products, machinery, or equipment
• Full-service contracts with a defined scope to maintain products
• Operation of the products at the customer's site/for the customer (e.g., pay on production)
• Taking over the management of maintenance activities for the customer to guarantee availability or costs
• Contracting offers (supply of operating resources such as compressed air, light, heat, cold, electricity, "chemical leasing").

Source: Own representation.

Appendix 6. Extent of the digital service portfolio – definition of groups

Group	Description
non-service-providers	firms that offer neither standard service nor advanced service.
manual standard services	firms that offer at least one standard service but do not use any digital service solutions
manual advanced services	firms that offer at least one advanced service but do not use any digital service solutions.
digital standard services	firms that offer at least one standard service and use at least one digital service solution.
digital advanced services	firms that offer at least one advanced service and use at least one digital service solution.

Source: Own representation.

Appendix 7. Correlation between scope, depth, and extent of the digital services

		Scope of digital service solutions			
		0	1	2	≥3
Extent of digital service portfolio	No service offers	13.3 %			
	Manual standard services	41.1 %			
	Manual advanced services	10.4 %			
	Digital standard services		10.3 %	5.6 %	1.9 %
	Digital advanced services		6.5 %	5.4 %	5.5 %

		Depth of digital service integration		
		SSP	SSC	SSP and SSC
Scope of digital service solutions	1	20.6 %	28.0 %	0.4 %
	2	7.8 %	11.9 %	10.5 %
	≥3	0.4 %	1.3 %	18.8 %

		Depth of digital service integration		
		SSP	SSC	SSP and SSC
Extent of digital service portfolio	Digital standard services	13.3 %	27.9 %	9.3 %
	Digital advanced services	16.3 %	12.3 %	20.9 %

Note: n = 1223. Considering all manufacturers, a statistically significant association is observed between scope and extent of the digital services ($p = 0.000$, Fisher's Exact test resp. $X^2 = 1315.531$ with $df = 12$, $p = 0.000$). Spearman's $\rho = 0.852$ ($p = 0.000$) indicates a fairly strong relationship. However, when considering digital service providers only according to the Spearman's $\rho = 0.254$ ($p < 0.0001$), the association is less relevant, even if still statistically significant ($p = 0.000$, Fisher's Exact test resp. $X^2 = 31.778$ with $df = 2$, $p = 0.000$).
Note: n = 445. Considering digital service providers, depth and scope are statistically significantly associated ($p = 0.000$, Fisher's Exact test resp. $X^2 = 255.590$ with $df = 4$, $p = 0.000$).
Note: n = 430. Considering digital service providers, depth and extent are statistically significantly associated ($p = 0.000$, Fisher's Exact test resp. $X^2 = 46.476$ with $df = 2$, $p = 0.000$).
Source: *German Manufacturing Survey* 2018,
own calculations.

Appendix 8. Further independent variables

Construct	Definition	Type of variable
Firm size	Number of employees in 2017, log-transformed to model the decreasing impact.	metric variable
Sectoral affiliation	Based on NACE classification rev. 2. Differentiating between (1) producers of food and beverage, (2) producers of chemicals and pharmaceuticals, (3) producers of rubber and plastic products, (4) machinery, (5) producers of electrical and electronic products, (6) producers of transport equipment, and (7) other manufacturers (incl. Textile and leather industry, paper and print industry, industry of petrol or non-metal products). Reference group: metal industry	nominal resp. 7 dummies
Product complexity	Degree of complexity of the main product, differentiating between (1) producers of simple products, and (2) producers of medium complex products. Reference group*:* producer of complex products	ordinal resp. 2 dummies
Batch size	Differentiating between (1) producers of single pieces, and (2) producers of small or medium sized batches/lots. Reference group*:* producer of large batches/lots.	ordinal resp. 2 dummies

Appendix 9. Level of digital servitization in light of its facets

Scope of digital service solutions					
# of digital service solutions offered	0	1	2	≥3	
Share of manufacturers*	64 %	17 %	11 %	7 %	
Depth of digital service integration					
Depth of digital service integration	SSP	SSC	SSP and SSC		
Share of digital service providers	29 %	41 %	30 %		
Share of manufacturers	10 %	15 %	11 %		
Extent of digital service portfolio					
Groups of digital service offerings	No service offer	Manual standard services	Manual advanced services	Digital standard services	Digital advanced services
Share of manufacturers*	13 %	41 %	10 %	18 %	17 %

Notes: *Slight deviation from total sum of 100 % due to rounded values.
Source: *German Manufacturing Survey* 2018,
own calculations.

Appendix 10. Share of firms by I4.0 level and by use of digital platforms

	I4.0 level *				Digital platform users
	Non-users	Beginners	Advanced users	Top group	
Share of manufacturers	14 %	54 %	25 %	8 %	16 %

Notes: * Slight Deviation from total sum of 100 % due to rounded values.
Source: *German Manufacturing Survey* 2018, own calculations.

Appendix 11. Main results of regression analyses for H1

Use of digital plattform	Scope of digital service solutions	Depth of digital service integration	Extent of digital service portfolio
	(H1a)	(H1b)	(H1c)
Firm size	***	***	***
Sector	**	n.s.	*
Product complexity	n.s.	n.s.	n.s.
Batch or lot size	n.s.	n.s.	n.s.
Level of digital servitization	***	***	***
N	1.158	417	1.132
Model sig.	***	***	***

Notes: Significance level: *$p < 0.1$; **$p < 0.05$; ***$p < 0.001$. Logistic models on manufacturing firms with reference to firms not using digital plattforms for services. Level of digital servitization measured by three separate indicators. Models (H1a) and (H1c) include manufacturing firms, model (H1b) includes manufacturing firms with digital service solutions only.
Source: *German Manufacturing Survey* 2018, own calculations.

Appendix 12. Main results of the regression analyses for H2

I4.0 level	Scope of digital service solutions			Depth of digital service integration			Extent of digital service portfolio		
	(H2a)			(H2b)			(H2c)		
	m1	m2	m3	m1	m2	m3	m1	m2	m3
Firm size	***	***	***	**	***	***	***	***	***
Sector	**	n.s.	*	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Product complexity	n.s.	**	**	n.s.	n.s.	**	n.s.	**	**
Batch or lot size	n.s.	*	n.s.	n.s.	n.s.	*	n.s.	**	n.s.
Level of digital servitization	**	**	n.s.	n.s.	n.s.	*	**	**	n.s.
N	1132	1132	1132	404	404	404	1107	1107	1107
Model sig.	***	***	***	n.s.	***	***	***	***	***

Notes: Significance level: *$p < 0.1$; **$p < 0.05$; ***$p < 0.001$. Logistic models on manufacturing firms with reference to firms using digital technologies in production (I4.0 level above 0) (m1), Firms using using no digital technology in production or only in one or two fields (I4.0 level below 2) (m2), Firms having not reached the I4.0 top level (m3). Level of digital servitization measured by three separate indicators. Models (H2a) and (H2c) include manufacturing firms, model (H2b) includes manufacturing firms with digital service solutions only.
Source: *German Manufacturing Survey* 2018, own calculations.

Appendix 13. Regression results for H1a and H2a, using the scope indicator

	Hypothesis 1		Hypothesis 2					
	(A)		(B)		(C)		(D)	
	digital platforms (a)		I4.0-level: non-users (b)		I4.0-level: advanced users/top group (c)		I4.0-level: top group (d)	
	OR	*sig.*	*OR*	*sig.*	*OR*	*sig.*	*OR*	*sig.*
firm size (log)	1,32	0,000	0,53	0,000	1,78	0,000	2,12	0,000
sector (NACE rev. 2) (1)		0,048		0,036	0,00	0,144		0,094
food, beverage and tobacco industry (10–12)	2,05	0,106	1,90	0,042	0,84	0,524	0,72	0,548
chemical industry (20 21)	2,72	0,035	2,09	0,092	0,54	0,109	1,06	0,919
rubber and plastic industry	1,59	0,195	1,14	0,652	0,74	0,198	0,75	0,511
machinery (28)	0,85	0,631	0,73	0,395	0,66	0,075	0,27	0,006
electronical/electrical engineering (26 27)	0,82	0,589	1,10	0,791	0,55	0,017	0,71	0,401
automotiv and transport equipment (29 30)	1,29	0,618	3,31	0,012	0,35	0,013	0,14	0,022
other manufacturers	2,01	0,036	1,58	0,095	0,71	0,122	0,94	0,886
product complexity (2)		0,641		0,079	0,00	0,001		0,004
simple products	0,90	0,752	1,82	0,036	0,44	0,000	0,37	0,016
products with medium complexity	1,14	0,556	1,22	0,415	0,68	0,017	0,42	0,002
batch or lot size (3)		0,180		0,463	0,00	0,084		0,298
single unit production	1,41	0,341	1,50	0,214	0,60	0,031	0,52	0,123
small or medium batch/lot	1,73	0,084	1,33	0,335	0,78	0,232	0,69	0,261
Scope of digital service solutions (4)		0,000		0,003	0,00	0,0012		0,122

(*continued on next page*)

(*continued*)

	Hypothesis 1		Hypothesis 2					
	(A)		(B)		(C)		(D)	
	digital platforms (a)		I4.0-level: non-users (b)		I4.0-level: advanced users/top group (c)		I4.0-level: top group (d)	
	OR	*sig.*	*OR*	*sig.*	*OR*	*sig.*	*OR*	*sig.*
one DSS	6,86	0,000	0,36	0,002	1,13	0,531	1,37	0,345
two DSS	13,80	0,000	0,40	0,029	1,55	0,052	1,35	0,467
three and more DSS	33,78	0,000	0,52	0,191	2,81	0,000	2,62	0,016
Intercept	0,01	0,000	1,23	0,743	0,09	0,000	0,01	0,000
N/sig	1158	0,000	1132	0,000	1132	0,000	1132	0,000
Sig of model		0,000		0,000		0,000		0,000
−2 Log-Likelihood		769,091a		823,796a		1271,361a		486,997a
Cox & Snell R-Quadrat		19,8 %		8,3 %		12,8 %		9,0 %
Nagelkerkes R-Quadrat		33,7 %		15,0 %		17,9 %		22,0 %

Notes: Logistic models on manufacturing firms with reference to (a) Firms not using digital platforms for services, (b) Firms using digital technologies in production (I4.0 level above 0), (c) Firms using no digital technology in production or only in one or two fields (I4.0 level below 2), (c) Firms having not reached the I4.0 top level. Modell fit: −2 log likelihood: (A) 769,091, (B) 823,796, (C) 1271,361, (D) 486,997.
Reference groups of independent: (1) Metal and metal products industry (NACE 24 25), (2) complex products, (3) large batch/lot, (4) no digital support techniques used.
Source: *German Manufacturing Survey* 2018, own calculations.

Appendix 14. Multinomial regression models as robustness check for H2a, using the scope indicator

Variables/Categories	Non-user vs. Beginners, log odds		Advanced users vs. Beginners, log odds		Top group vs. Beginners, log odds		Construct
	OR/sig	95 % CI	*OR/sig*	95 % CI	*OR/sig*	95 % CI	p-Value
Firm size [# of employees] (log)	0,62**	[0,486; 0,800]	1,50**	[1292; 1751]	2,48 **	[1968; 3131]	0,000
Sector (NACE rev. 2): *Reference groups: Metal and metal products industry (NACE 24 25)*							0,019
food, beverage, tobacco (10–12)	1,89*	[0,988; 3605]	1,02	[0,568; 1844]	0,76	[0,253; 2309]	
chemical industry (20, 21)	1,81	[0,747; 4367]	0,53	[0,221; 1266]	0,89	[0,263; 3044]	
Rubber/plastics, glass/stone (22, 23)	1,05	[0,585; 1895]	0,77	[0,466; 1258]	0,68	[0,276; 1659]	
machinery (28)	0,65	[0,305; 1362]	0,75	[0,463; 1219]	0,25 **	[0,098; 0,639]	
electronical/electrical engin. (26, 27)	0,92	[0,434; 1956]	0,52**	[0,304; 0,903]	0,54	[0,231; 1249]	
automotive/transport equip. (29, 30)	2,58*	[0,993; 6712]	0,52	[0,217; 1254]	0,12 **	[0,023; 0,676]	
other manufacturers	1,45	[0,830; 2530]	0,73	[0,449; 1184]	0,86	[0,383; 1931]	
Product complexity: *Reference groups: complex products*							0,002
simple products	1,47	[0,827; 2607]	0,53**	[0,318; 0,871]	0,31 **	[0,133; 0,725]	
products with medium complexity	1,09	[0,664; 1782]	0,78	[0,547; 1105]	0,39 **	[0,218; 0,685]	
Batch or lot size: *Reference groups: large batch/lot*							0,390
single unit production	1,31	[0,679; 2509]	0,68	[0,409; 1148]	0,46 *	[0,198; 1086]	
small or medium batch/lot	1,25	[0,691; 2248]	0,88	[0,562; 1367]	0,68	[0,348; 1321]	
Scope of digital service solutions: *Reference groups: no DSS*							0,000
one DSS	0,36**	[0,187; 0,682]	*0,93*	[0,620; 1402]	1,20	[0,610; 2364]	
two DSS	0,44*	[0,191; 1025]	*1,39*	[0,863; 2234]	1,42	[0,626; 3240]	
three or more DSS	0,77	[0,274; 2157]	2,44**	[1361; 4374]	3,86 **	[1662; 8948]	
Intercept	-	–	- ***	-	- ***		

Note: The fit between the model containing only the intercept and data improved with the addition of the predictor variables, LR X^2 (df = 45, N = 1.132) = 259,453, Nagelkerke R2 = 0.228, p < 0.001. A multinomial logistic regression was performed to create a model of the relationship between the predictor variables and the I4.0 levels, which differentiates four groups (non-users, beginners, advanced users, and the top group). The beginner group is set as the reference, so the table shows the odds ratios for each response relative to the beginners. Significance level: *p < 0,1; **p < 0,05; ***p < 0,001. CI: Confidence interval.
The main results support the above presented logistic regression estimations. Except for batch size, all constructs contribute statistically significantly to the model at least at the 5 % level. Firm size is positively linked to a higher I4.0 level, as is the estimated impact of product complexity.
Source: *German Manufacturing Survey* 2018, own calculations.

Data availability

The authors do not have permission to share data.

References

Baines, T., Lightfoot, H., Peppard, J., Johnson, M., Tiwari, A., Shehab, E., Swink, M., 2009. Towards an operations strategy for product-centric servitization. Int. J. Oper. Prod. Manag. 29, 494–519. https://doi.org/10.1108/01443570910953603.

Baines, T., Lightfoot, H., Smart, P., Fletcher, S., 2013. Servitization of manufacture: exploring the deployment and skills of people critical to the delivery of advanced services. J. Manuf. Technol. Manag. 24, 637–646. https://doi.org/10.1108/17410381311327431.

Baines, T., Lightfoot, H.W., 2014. Servitization of the manufacturing firm: exploring the operations practices and technologies that deliver advanced services. Int. J. Oper. Prod. Manag. 34, 2–35. https://doi.org/10.1108/IJOPM-02-2012-0086.

Baines, T., Ziaee Bigdeli, A., Bustinza, O.F., Shi, V.G., Baldwin, J., Ridgway, K., 2017. Servitization: revisiting the state-of-the-art and research priorities. Int. J. Oper. Prod. Manag. 37, 256–278. https://doi.org/10.1108/IJOPM-06-2015-0312.

Bask, A., Lipponen, M., Rajahonka, M., Tinnilä, M., 2010. The concept of modularity: diffusion from manufacturing to service production. J. Manuf. Technol. Manag. 21, 355–375. https://doi.org/10.1108/17410381011024331.

Bavdaž, M., Snijkers, G., Sakshaug, J.W., Brand, T., Haraldsen, G., Kurban, B., Saraiva, P., Willimack, D.K., 2020. Business data collection methodology: current state and future outlook. Stat. J. IAOS 36, 741–756. https://doi.org/10.3233/SJI-200623.

Belvedere, V., Grando, A., Bielli, P., 2013. A quantitative investigation of the role of information and communication technologies in the implementation of a product-service system. Int. J. Prod. Res. 51, 410–426. https://doi.org/10.1080/00207543.2011.648278.

Biesinger, B., Hadwich, K., Bruhn, M., 2024. Cultural change in servitization – a conceptual review and framework. J. Serv. Theory Pract. https://doi.org/10.1108/JSTP-03-2023-0074.

Blichfeldt, H., Faullant, R., 2021. Performance effects of digital technology adoption and product & service innovation – a process-industry perspective. Technovation 105. https://doi.org/10.1016/j.technovation.2021.102275.

Bortoluzzi, G., Chiarvesio, M., Romanello, R., Tabacco, R., Veglio, V., 2020. Industry 4.0 technologies and the servitization strategy: a good match? Sinergie ital. J. Manag. 38.

Brandstotter, Haberl, Knoth, Kopacek, Kopacek, 2003. IT on demand - towards an environmental conscious service system for Vienna (AT). In: 2003 Ecodesign 3rd International Symposium on Environmentally Conscious Design and Inverse Manufacturing. IEEE, pp. 799–802. https://doi.org/10.1109/ECODIM.2003.1322776.

Cannavacciuolo, L., Ferraro, G., Ponsiglione, C., Primario, S., Quinto, I., 2023. Technological innovation-enabling industry 4.0 paradigm: a systematic literature review. Technovation 124, 102733. https://doi.org/10.1016/j.technovation.2023.102733.

Cenamor, J., Rönnberg Sjödin, D., Parida, V., 2017. Adopting a platform approach in servitization: leveraging the value of digitalization. Int. J. Prod. Econ. 192, 54–65. https://doi.org/10.1016/j.ijpe.2016.12.033.

Coreynen, W., Matthyssens, P., Van Bockhaven, W., 2017. Boosting servitization through digitization: pathways and dynamic resource configurations for manufacturers. Ind. Mark. Manag. 60, 42–53. https://doi.org/10.1016/j.indmarman.2016.04.012.

Coreynen, W., Matthyssens, P., Vanderstraeten, J., van Witteloostuijn, A., 2020. Unravelling the internal and external drivers of digital servitization: a dynamic capabilities and contingency perspective on firm strategy. Ind. Mark. Manag. 89, 265–277. https://doi.org/10.1016/j.indmarman.2020.02.014.

Crossan, M.M., Lane, H.W., White, R.E., 1999. An organizational learning framework: from intuition to institution. Acad. Manag. Rev. 24, 522–537. https://doi.org/10.5465/amr.1999.2202135.

Cusumano, M.A., Kahl, S.J., Suarez, F.F., 2015. Services, industry evolution, and the competitive strategies of product firms. Strateg. Manag. J. 36, 559–575. https://doi.org/10.1002/smj.2235.

Dachs, B., Biege, S., Borowiecki, M., Lay, G., Jäger, A., Schartinger, D., 2013. Servitisation of European manufacturing: evidence from a large scale database. Serv. Ind. J. 34, 5–23. https://doi.org/10.1080/02642069.2013.776543.

Dachs, B., Kinkel, S., Jäger, A., 2019. Bringing it all back home? Backshoring of manufacturing activities and the adoption of industry 4.0 technologies. J. World Bus. 54, 101017. https://doi.org/10.1016/j.jwb.2019.101017.

Dalenogare, L.S., Benitez, G.B., Ayala, N.F., Frank, A.G., 2018. The expected contribution of industry 4.0 technologies for industrial performance. Int. J. Prod. Econ. 204, 383–394. https://doi.org/10.1016/j.ijpe.2018.08.019.

Dalenogare, L.S., Le Dain, M.-A.A., Ayala, N.F., Pezzotta, G., Frank, A.G., 2023. Building digital servitization ecosystems: an analysis of inter-firm collaboration types and social exchange mechanisms among actors. Technovation 124, 102756. https://doi.org/10.1016/j.technovation.2023.102756.

Duszynski, T.J., Fadel, W., Dixon, B.E., Yiannoutsos, C., Halverson, P.K., Menachemi, N., 2022. Successive wave analysis to assess nonresponse bias in a statewide random sample testing study for SARS-CoV-2. J. Publ. Health Manag. Pract. 28, E685–E691. https://doi.org/10.1097/PHH.0000000000001508.

Easterby-Smith, M., Crossan, M., Nicolini, D., 2000. Organizational learning: debates past, present and future. J. Manag. Stud. 37, 783–796. https://doi.org/10.1111/1467-6486.00203.

Eloranta, V., Ardolino, M., Saccani, N., 2021. A complexity management approach to servitization: the role of digital platforms. Int. J. Oper. Prod. Manag. 41, 622–644. https://doi.org/10.1108/IJOPM-08-2020-0582.

Eloranta, V., Turunen, T., 2016. Platforms in service-driven manufacturing: leveraging complexity by connecting, sharing, and integrating. Ind. Mark. Manag. 55, 178–186. https://doi.org/10.1016/j.indmarman.2015.10.003.

Ennis, C., Barnett, N., De Cesare, S., Lander, R., Pilkington, A., 2020. A Conceptual Framework for Servitization in Industry 4.0: Distilling Directions for Future Research. SSRN Electron. J. https://doi.org/10.2139/ssrn.3529276.

Fang, X., Liu, M., 2024. How does the digital transformation drive digital technology innovation of enterprises? Evidence from enterprise’s digital patents. Technol. Forecast. Soc. Change 204, 123428. https://doi.org/10.1016/j.techfore.2024.123428.

Fliess, S., Lexutt, E., 2019. How to be successful with servitization – guidelines for research and management. Ind. Mark. Manag. 78, 58–75. https://doi.org/10.1016/j.indmarman.2017.11.012.

Frank, A., Dalenogare, L., Ayala, N., 2019a. Industry 4.0 technologies: implementation patterns in manufacturing companies. Int. J. Prod. Econ. 210, 15–26. https://doi.org/10.1016/j.ijpe.2019.01.004.

Frank, A., Mendes, G., Ayala, N., Ghezzi, A., 2019b. Servitization and industry 4.0 convergence in the digital transformation of product firms: a business model innovation perspective. Technol. Forecast. Soc. Change 141, 341–351. https://doi.org/10.1016/j.techfore.2019.01.014.

Fraunhofer Institute for Systems and Innovation Research ISI, 2024. European manufacturing survey. https://www.isi.fraunhofer.de/en/themen/wertschoepfung/fems.html. (Accessed 7 December 2024).

Gaiardelli, P., Pezzotta, G., Rondini, A., Romero, D., Jarrahi, F., Bertoni, M., Wiesner, S., Wuest, T., Larsson, T., Zaki, M., Jussen, P., Boucher, X., Bigdeli, A.Z., Cavalieri, S., 2021. Product-service systems evolution in the era of industry 4.0. Serv. Bus. 15, 177–207. https://doi.org/10.1007/s11628-021-00438-9.

Garzoni, A., De Turi, I., Secundo, G., Del Vecchio, P., 2020. Fostering digital transformation of SMEs: a four levels approach. Manag. Decis. 58, 1543–1562. https://doi.org/10.1108/MD-07-2019-0939.

Gebauer, H., Friedli, T., Fleisch, E., 2006. Success factors for achieving high service revenues in manufacturing companies. Benchmarking An Int. J. 13, 374–386. https://doi.org/10.1108/14635770610668848.

Gebauer, H., Paiola, M., Saccani, N., Rapaccini, M., 2021. Digital servitization: crossing the perspectives of digitization and servitization. Ind. Mark. Manag. 93, 382–388. https://doi.org/10.1016/j.indmarman.2020.05.011.

Gradillas, M., Thomas, L.D.W., 2023. Distinguishing digitization and digitalization: a systematic review and conceptual framework. J. Prod. Innovat. Manag. 1–32. https://doi.org/10.1111/jpim.12690.

Grönroos, C., Voima, P., 2013. Critical service logic: making sense of value creation and co-creation. J. Acad. Market. Sci. 41, 133–150. https://doi.org/10.1007/s11747-012-0308-3.

Haaker, T., Ly, P.T.M., Nguyen-Thanh, N., Nguyen, H.T.H., 2021. Business model innovation through the application of the Internet-of-Things: a comparative analysis. J. Bus. Res. 126, 126–136. https://doi.org/10.1016/j.jbusres.2020.12.034.

Horvat, D., Kroll, H., Jäger, A., 2019. Researching the effects of automation and digitalization on manufacturing companies’ productivity in the early stage of industry 4.0. Procedia Manuf. 886–893. https://doi.org/10.1016/j.promfg.2020.01.401.

Huikkola, T., Kohtamäki, M., Ylimäki, J., 2022. Becoming a smart solution provider: reconfiguring a product manufacturer’s strategic capabilities and processes to facilitate business model innovation. Technovation 118. https://doi.org/10.1016/j.technovation.2022.102498.

Jäger, A., Lerch, C., 2020. Readiness for Industry 4.0: Insights into the Upper-Rhine Region. Karlsruhe.

Jäger, A., Maloca, S., 2019. Dokumentation Der Umfrage Modernisierung Der Produktion 2018. Karlsruhe.

Jha, A.K., Bose, I., Ngai, E.W.T., 2016. Platform based innovation: the case of bosch India. Int. J. Prod. Econ. 171, 250–265. https://doi.org/10.1016/j.ijpe.2015.09.037.

Kagermann, H., 2015. Change through digitization—value creation in the age of industry 4.0. In: Management of Permanent Change. Springer, Fachmedien Wiesbaden, Wiesbaden, pp. 23–45. https://doi.org/10.1007/978-3-658-05014-6_2.

Kapoor, K., Bigdeli, A.Z., Dwivedi, Y.K., Raman, R., 2024. How is COVID-19 altering the manufacturing landscape? A literature review of imminent challenges and management interventions. Ann. Oper. Res. 335, 1567–1599. https://doi.org/10.1007/s10479-021-04397-2.

Kapoor, K., Bigdeli, A.Z., Schroeder, A., Baines, T., 2022. A platform ecosystem view of servitization in manufacturing. Technovation 118, 102248. https://doi.org/10.1016/j.technovation.2021.102248.

Kinkel, S., Baumgartner, M., Cherubini, E., 2022. Prerequisites for the adoption of AI technologies in manufacturing – evidence from a worldwide sample of manufacturing companies. Technovation 110. https://doi.org/10.1016/j.technovation.2021.102375.

Kinkel, S., Beiner, S., Fara, D.R., 2023. Key competences for digital business model innovation of industrial companies. Int. J. Innovat. Manag. 27. https://doi.org/10.1142/S1363919623400029.

Kohtamäki, M., Parida, V., Oghazi, P., Gebauer, H., Baines, T., 2019. Digital servitization business models in ecosystems: a theory of the firm. J. Bus. Res. 104, 380–392. https://doi.org/10.1016/j.jbusres.2019.06.027.

Kohtamäki, M., Parida, V., Patel, P.C., Gebauer, H., 2020. The relationship between digitalization and servitization: the role of servitization in capturing the financial potential of digitalization. Technol. Forecast. Soc. Change 151, 119804. https://doi.org/10.1016/j.techfore.2019.119804.

Kolagar, M., Parida, V., Sjödin, D., 2022. Ecosystem transformation for digital servitization: a systematic review, integrative framework, and future research agenda. J. Bus. Res. 146, 176–200. https://doi.org/10.1016/j.jbusres.2022.03.067.

Kowalkowski, C., Kindström, D., Gebauer, H., 2013. ICT as a catalyst for service business orientation. J. Bus. Ind. Market. 28, 506–513. https://doi.org/10.1108/JBIM-04-2013-0096.

Lay, G., Copani, G., Jäger, A., Biege, S., 2010. The relevance of service in European manufacturing industries. J. Serv. Manag. 21, 715–726. https://doi.org/10.1108/09564231011092908.

Lenka, S., Parida, V., Wincent, J., 2017. Digitalization capabilities as enablers of value co-creation in servitizing firms. Psychol. Market. 34, 92–100. https://doi.org/10.1002/mar.20975.

Lerch, C., Gotsch, M., 2015. Digitalized product-service systems in manufacturing firms: a case study analysis. Res. Manag. 58, 45–52. https://doi.org/10.5437/08956308X5805357.

Lerch, C.M., Horvat, D., Jasny, J., 2024. When manufacturers turn into digital platform providers: a transformation model to understand the platformization pathway. Int. J. Prod. Econ. 273, 109235. https://doi.org/10.1016/j.ijpe.2024.109235.

Liao, Y., Deschamps, F., Loures, E. de F.R., Ramos, L.F.P., 2017. Past, present and future of industry 4.0 - a systematic literature review and research agenda proposal. Int. J. Prod. Res. 55, 3609–3629. https://doi.org/10.1080/00207543.2017.1308576.

Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E., Schröter, M., 2015. Industrie 4.0 readiness. Impuls. des VMDA Aachen-Köln 52.

Lightfoot, H., Baines, T., Smart, P., 2013. The servitization of manufacturing. Int. J. Oper. Prod. Manag. 33, 1408–1434. https://doi.org/10.1108/IJOPM-07-2010-0196.

Long, J.S., Freese, J., 2014. Regression Models for Categorical Dependent Variables Using Stata, third ed. Stata Press.

Marcon, É., Marcon, A., Ayala, N.F., Frank, A.G., Story, V., Burton, J., Raddats, C., Zolkiewski, J., 2022. Capabilities supporting digital servitization: a multi-actor perspective. Ind. Mark. Manag. 103, 97–116. https://doi.org/10.1016/j.indmarman.2022.03.003.

Marques, P., Bikfalvi, A., Simon, A., Llach, J., Lerch, C., 2015. Servitisation and technological complexity in family and non-family firms: european evidence. Eur. J. Int. Manag. 9, 221. https://doi.org/10.1504/EJIM.2015.067855.

Mathieu, V., 2001. Product services: from a service supporting the product to a service supporting the client. J. Bus. Ind. Market. 16, 39–61. https://doi.org/10.1108/08858620110364873.

Matthyssens, P., Vandenbempt, K., 2010. Service addition as business market strategy: identification of transition trajectories. J. Serv. Manag. 21, 693–714. https://doi.org/10.1108/09564231011079101.

Meyer, M.H., Lehnerd, A.P., 1997. The power of product platforms. Building Value and Cost Leadership. Free Press, New York.

Minaya, P.E., Avella, L., Trespalacios, J.A., 2024. Synthesizing three decades of digital servitization: a systematic literature review and conceptual framework proposal. Serv. Bus. 18, 193–222. https://doi.org/10.1007/s11628-024-00559-x.

Momeni, K., Raddats, C., Martinsuo, M., 2023. Mechanisms for developing operational capabilities in digital servitization. Int. J. Oper. Prod. Manag. 43, 101–127. https://doi.org/10.1108/IJOPM-04-2022-0259.

Müller, J.M., Buliga, O., Voigt, K.-I., 2018. Fortune favors the prepared: how SMEs approach business model innovations in industry 4.0. Technol. Forecast. Soc. Change 132, 2–17. https://doi.org/10.1016/j.techfore.2017.12.019.

Münch, C., Marx, E., Benz, L., Hartmann, E., Matzner, M., 2022. Capabilities of digital servitization: evidence from the socio-technical systems theory. Technol. Forecast. Soc. Change 176, 121361. https://doi.org/10.1016/j.techfore.2021.121361.

Narula, S., Prakash, S., Dwivedy, M., Talwar, V., Tiwari, S.P., 2020. Industry 4.0 adoption key factors: an empirical study on manufacturing industry. J. Adv. Manag. Res. 17, 697–725. https://doi.org/10.1108/JAMR-03-2020-0039.

Oliva, R., Kallenberg, R., 2003. Managing the transition from products to services. Int. J. Serv. Ind. Manag. 14, 160–172. https://doi.org/10.1108/09564230310474138.

Paiola, M., Gebauer, H., 2020. Internet of things technologies, digital servitization and business model innovation in BtoB manufacturing firms. Ind. Mark. Manag. 89, 245–264. https://doi.org/10.1016/j.indmarman.2020.03.009.

Paiola, M., Schiavone, F., Khvatova, T., Grandinetti, R., 2021. Prior knowledge, industry 4.0 and digital servitization. An inductive framework. Technol. Forecast. Soc. Change 171, 120963. https://doi.org/10.1016/j.techfore.2021.120963.

Palčič, I., Klančnik, S., Lerher, T., Ficko, M., 2020. The use of digital factory technologies in Slovenian manufacturing companies. In: Karabegović, I. (Ed.), New Technologies, Development and Application III, pp. 227–237.

Paschou, T., Rapaccini, M., Adrodegari, F., Saccani, N., 2020. Digital servitization in manufacturing: a systematic literature review and research agenda. Ind. Mark. Manag. 89, 278–292. https://doi.org/10.1016/j.indmarman.2020.02.012.

Pauli, T., Fielt, E., Matzner, M., 2021. Digital industrial platforms. Bus. Inf. Syst. Eng. 63, 181–190. https://doi.org/10.1007/s12599-020-00681-w.

Penttinen, E., Palmer, J., 2007. Improving firm positioning through enhanced offerings and buyer–seller relationships. Ind. Mark. Manag. 36, 552–564. https://doi.org/10.1016/j.indmarman.2006.02.005.

Pirola, F., Boucher, X., Wiesner, S., Pezzotta, G., 2020. Digital technologies in product-service systems: a literature review and a research agenda. Comput. Ind. 123, 103301. https://doi.org/10.1016/j.compind.2020.103301.

Raddats, C., Burton, J., Ashman, R., 2015. Resource configurations for services success in manufacturing companies. J. Serv. Manag. 26, 97–116. https://doi.org/10.1108/JOSM-12-2012-0278.

Raddats, C., Kowalkowski, C., Benedettini, O., Burton, J., Gebauer, H., 2019. Servitization: a contemporary thematic review of four major research streams. Ind. Mark. Manag. 83, 207–223. https://doi.org/10.1016/j.indmarman.2019.03.015.

Rapaccini, M., Paiola, M., Cinquini, L., Giannetti, R., 2023. Digital servitization journey in small- and medium-sized enterprises: the contribution of knowledge-intensive business firms. J. Bus. Ind. Market. 38, 1362–1375. https://doi.org/10.1108/JBIM-01-2022-0008.

Ritala, P., Keränen, J., Fishburn, J., Ruokonen, M., 2024. Selling and monetizing data in B2B markets: four data-driven value propositions. Technovation 130. https://doi.org/10.1016/j.technovation.2023.102935.

Rönnberg Sjödin, D., Parida, V., Kohtamäki, M., 2016. Capability configurations for advanced service offerings in manufacturing firms: using fuzzy set qualitative comparative analysis. J. Bus. Res. 69, 5330–5335. https://doi.org/10.1016/j.jbusres.2016.04.133.

Rupp, M., Schneckenburger, M., Merkel, M., Börret, R., Harrison, D.K., 2021. Industry 4.0: a technological-oriented definition based on bibliometric analysis and literature review. J Open Innov. Technol. Mark. Complex. 7, 68. https://doi.org/10.3390/joitmc7010068.

Rymaszewska, A., Helo, P., Gunasekaran, A., 2017. IoT powered servitization of manufacturing – an exploratory case study. Int. J. Prod. Econ. 192, 92–105. https://doi.org/10.1016/j.ijpe.2017.02.016.

Sakshaug, J.W., Vicari, B., Couper, M.P., 2019. Paper, E-mail, or both? Effects of contact mode on participation in a web survey of establishments. Soc. Sci. Comput. Rev. 37, 750–765. https://doi.org/10.1177/0894439318805160.

Shen, L., Sun, W., Parida, V., 2023. Consolidating digital servitization research: a systematic review, integrative framework, and future research directions. Technol. Forecast. Soc. Change 191, 122478. https://doi.org/10.1016/j.techfore.2023.122478.

Simonsson, J., Magnusson, M., Johanson, A., 2020. Organizing the development of digital product-service platforms. Technol. Innov. Manag. Rev. 10, 37–48. https://doi.org/10.22215/timreview/1335.

Sklyar, A., Kowalkowski, C., Tronvoll, B., Sörhammar, D., 2019. Organizing for digital servitization: a service ecosystem perspective. J. Bus. Res. 104, 450–460. https://doi.org/10.1016/j.jbusres.2019.02.012.

Soellner, S., Helm, R., Klee, P., Endres, H., 2024. Industrial service innovation: exploring the transformation process to digital servitization in industrial goods companies. Ind. Mark. Manag. 117, 288–303. https://doi.org/10.1016/j.indmarman.2024.01.009.

Sony, M., Naik, S., 2020. Critical factors for the successful implementation of industry 4.0: a review and future research direction. Prod. Plan. Control 31, 799–815. https://doi.org/10.1080/09537287.2019.1691278.

Tian, J., Coreynen, W., Matthyssens, P., Shen, L., 2022. Platform-based servitization and business model adaptation by established manufacturers. Technovation 118, 102222. https://doi.org/10.1016/j.technovation.2021.102222.

Tukker, A., 2004. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Bus. Strat. Environ. 13, 246–260. https://doi.org/10.1002/bse.414.

Tuttle, A.D., Beck, J.L., Willimack, D.K., Tolliver, K.P., Hernandez, A., Fan, C.C., 2018. Experimenting with contact strategies in business surveys. J. Off. Stat. 34, 365–395. https://doi.org/10.2478/jos-2018-0017.

Ulaga, W., Reinartz, W.J., 2011. Hybrid offerings: how manufacturing firms combine goods and services successfully. J. Market. 75, 5–23. https://doi.org/10.1509/jm.09.0395.

Valtakoski, A., 2017. Explaining servitization failure and deservitization: a knowledge-based perspective. Ind. Mark. Manag. 60, 138–150. https://doi.org/10.1016/j.indmarman.2016.04.009.

Vandermerwe, S., Rada, J., 1988. Servitization of business: adding value by adding services. Eur. Manag. J. 6, 314–324. https://doi.org/10.1016/0263-2373(88)90033-3.

Velamuri, V.K., Neyer, A.-K., Möslein, K.M., 2011. Hybrid value creation: a systematic review of an evolving research area. J. Betriebswirtschaft 61, 3–35. https://doi.org/10.1007/s11301-011-0070-5.

Vendrell-Herrero, F., Bustinza, O.F., Parry, G., Georgantzis, N., 2017. Servitization, digitization and supply chain interdependency. Ind. Mark. Manag. 60, 69–81. https://doi.org/10.1016/j.indmarman.2016.06.013.

Weking, J., Stöcker, M., Kowalkiewicz, M., Böhm, M., Krcmar, H., 2020. Leveraging industry 4.0 – a business model pattern framework. Int. J. Prod. Econ. 225, 107588. https://doi.org/10.1016/j.ijpe.2019.107588.

Zancul, E. de S., Takey, S.M., Barquet, A.P.B., Kuwabara, L.H., Cauchick Miguel, P.A., Rozenfeld, H., 2016. Business process support for IoT based product-service systems (PSS). Bus. Process Manag. J. 22, 305–323. https://doi.org/10.1108/BPMJ-05-2015-0078.

Zhao, J., Gao, P., 2024. Configurations of ambidextrous innovation and its performance implication in the context of digital transformation. Systems 12. https://doi.org/10.3390/systems12020060.

Zhu, Q., Krikke, H., Caniëls, M.C.J., 2018. Supply chain integration: value creation through managing inter-organizational learning. Int. J. Oper. Prod. Manag. 38, 211–229. https://doi.org/10.1108/IJOPM-06-2015-0372.