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Fischer, Isabel; Papert, Marcel; Leischnig, Alexander; Prockl, Günter

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An activity system perspective on smart product service systems

Isabel Fischer^a, Marcel Papert^{a,*}, Alexander Leischnig^b, Günter Prockl^{c,d}^a Department of Supply Chain Management, University of Bamberg, Feldkirchenstraße 21, 96052, Bamberg, Germany^b Technische Universität Bergakademie Freiberg, Schlossplatz 1, 09599, Freiberg, Germany^c Department of Digitalization, Copenhagen Business School, Howitzvej 60, 2000, Frederiksberg, Denmark^d Faculty of Business Administration, Prague University of Economics and Business VŠE, W. Churchill Sq. 1938/4, 130 67 Prague 3, Czech Republic

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ABSTRACT

Smart product-service systems (PSS) offer manufacturers the potential to create superior value for customers. Their development and commercialization, however, often force manufacturers to complement own competencies and resources with those from external partners, thus underlining the need for strategic collaboration. This paper aims to advance the knowledge about smart PSS by analyzing configurations of actors and activities that contribute to the creation smart PSS. Using an activity system perspective and a configurational approach, we explain the creation of smart PSS. Using fuzzy-set Qualitative Comparative Analysis (fsQCA), we analyze data from a qualitative study and identify two equifinal configurations for the creation of smart PSS. Our findings advance the smart PSS literature by uncovering the interplay between critical parameters of an activity system and environmental factors. As a managerial contribution, we provide templates for designing new activity systems to generate smart PSS.

1. Introduction

Smart product-service systems (PSS) integrate physical products, digital technologies, and service offerings to generate superior value for customers (Chen et al., 2020). They utilize microelectronics and software applications to perform various functions, including monitoring or remote control of the produced hardware to fulfill superior customer needs (e.g., Valencia et al., 2015; Zheng et al., 2019). The competencies and resources required to develop and commercialize smart PSS often go beyond those of the manufacturer's original domain, prompting manufacturers to collaborate with external providers to create valuable product-service bundles (e.g., Dalenogare et al., 2022; Fitzgerald et al., 2014). As a consequence, the locus of value creation shifts at least partially from the organizational production system to the external network, leading to new organization architectures (Heirati et al., 2024) and the need to align diverse activities from multiple actors (e.g., Hohmann and Posselt, 2019; Thornton et al., 2019).

The purpose of our study is to advance the knowledge about smart PSS by analyzing the network of actors and activities that contribute to the creation of valuable smart PSS. Prior research on smart PSS reveals that manufacturers need to orchestrate different competencies and

behaviors (Koldewey et al., 2022), and that actors other than the manufacturer can have important roles in building and implementing smart PSS (Sassanelli and Pacheco, 2024). For example, the management of data from different sources can create data integration challenges that have implications for digital service delivery. As a consequence, some manufacturers invest in network capabilities to build effective service ecosystems with external partners (Dalenogare et al., 2022). While some manufacturers may prefer to collaborate with external partners that perform a wide range of activities (generalists), others may favor collaboration with external partners that focus on specific activities (specialists). The decision to collaborate with generalists, specialists, or a combination of generalists and specialists in certain areas in the development and commercialization of smart PSS is a nontrivial one for manufacturers. For example, it may incur high transaction costs, create lock-in effects, and impact execution times and the time-to market. In addition, environmental demands may influence the effectiveness of actor-activity constellations to successfully develop and commercialize smart PSS and may imply alternative arrangements depending on the particular market situation in which a manufacturer operates. Prior work suggests that the composition of a firm's activity system may evolve over time as the environment in which the firm

* Corresponding author.

E-mail addresses: isabel.fischer@uni-bamberg.de (I. Fischer), marcel.papert@uni-bamberg.de (M. Papert), alexander.leischnig@bwl.tu-freiberg.de (A. Leischnig), gp.digi@cbs.dk (G. Prockl).

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operates changes (Zott and Amit, 2010). Environmental changes can have a fit-destroying or fit-conserving nature, thus creating different challenges for firms to orchestrate activities (Siggelkow, 2001).

Using an activity system perspective (Zott and Amit, 2010) as the guiding theoretical lens, we aim to examine the interplay between actor diversity, activity diversity, customer demand and environmental volatility to explain the creation of valuable smart PSS for customers. The primary research question is: *How do manufacturing firms configure their activity system to create valuable smart PSS for customers?* We aim to answer this question from the manufacturers' perspective by examining firms operating in the equipment and machinery industry. Using qualitative research, we collect rich data and analyze them with fuzzy-set Qualitative Comparative Analysis (fsQCA; Ragin, 2008). fsQCA is a set-theoretic method that describes the relationships between the conditions under study in terms of set relations. It helps to uncover configurations of multiple antecedent conditions sufficient for an outcome condition of interest. As such, fsQCA is particularly useful for illuminating multifaceted phenomena and has sparked several studies in the

business, IS and technology management literatures (e.g., Kumar et al., 2022; Park et al., 2020).

The results of our configuration analysis reveal multiple, consistently sufficient configurations that lead to valuable smart PSS. This knowledge adds to prior work by advancing the understanding of compound antecedents of smart PSS creation. The presence of multiple configurations indicates equifinality (Fiss, 2011) and suggests that alternative approaches for structuring the activity system can be successful. Hence, our study contributes to the strategic perspective on smart PSS by providing an integrative understanding of their creation (Münch et al., 2022). Analysis of typical cases for each configuration offered additional insight into particular actor-activity constellations used by manufacturers to create valuable smart PSS, thus providing a more nuanced and fine-grained understanding. Overall, our results add to existing work that has looked at the role of particular actor groups (such as customers; Sassanelli and Pacheco, 2024) and ecosystems (Koldewey et al., 2022) for achieving smart PSS. It also contributes to the literature on servitization by offering a more detailed understanding of how organization

Table 1
Key empirical research on smart PSS.

Article	Focus	Outcome(s)	Antecedents	Method	Consideration of	
					Activity system factors	Environmental factors
Kropp and Totzek (2020)	Business customer acceptance of smart PSS	Intention to adopt smart PSS	Mimetic pressure, normative pressure, coercive pressure, relative advantage of PSS, PSS type	Regression analysis; $n = 160$ B2B firms	NO	NO
Wang et al. (2021)	Graph-based context-aware requirement elicitation approach in smart PSS	Requirements on smart PSS	Context, products, services, interactions	Experiment; 100 comments about bike ridings	NO	YES
Tseng et al. (2021)	Smart PSS hierarchical model for the banking industry under uncertainties	Smart PSS performance	Institutional compression, digital platform operation, security structure, intelligent interaction, servitization system innovation, e-knowledge management, coordination and integration, organization capacity and performance	Fuzzy delphi method; 30 experts	YES	NO
Dalenogare et al. (2022)	Multichannel digital services and service ecosystems for smart PSS	PSS business models	Data integration, virtually augmented systems, cloud systems, smart products	Regression analyses; $n = 92$ manufacturing firms	YES	NO
Ferreira et al. (2022)	Key factors influencing the integration of smart PSS within an automotive company	Implementation of smart PSS	Business model, contracts, marketing, relationship network, design, sustainability, organizational and human management	Case study in an automotive company	YES	NO
Münch et al. (2022)	Capabilities required for the development and provision of smart PSS	Digital servitization	Goals, people, processes, culture, infrastructure, technologies, economic circumstances, stakeholders, regulatory frameworks	Case study based on four manufacturing companies	NO	YES
Dalenogare et al. (2023)	Inter-firm collaboration types and social exchange mechanisms for smart PSS	Provision of digital servitization (smart PSS)	Symbiotic business, platform business, enhanced business, expanded business, trust, commitment, power, reciprocity	Case study based on four cases across various industries	NO	NO
Bag et al. (2024)	Smart PSS capabilities for circular supply chains	Smart circular product-service systems capabilities, financial performance, environmental performance	Product lifetime database creation capabilities, analytics and business intelligence capabilities, actuating capabilities, environmental dynamism	Structural equation modeling; $n = 202$ manufacturing firms	NO	YES
Sassanelli and Pacheco (2024)	Impact of internet of things on perceived quality and customer involvement of smart PSS	Perceived quality, customer involvement/ engagement	Internet of things technologies	Mixed-method approach	NO	NO
Kohtamäki et al. (2025)	Emergence of artificial intelligence-enabled PSS for autonomous solutions	Capabilities and managerial practices for the transformation toward artificial intelligence-enabled PSS	Technology solutions, transformation process, organizational characteristics, business model architecture, historical events and decisions	Case study based on one manufacturing company	YES	NO
This study	Activity systems for the creation of smart PSS	Creation of valuable smart PSS	Actor diversity, activity diversity, customer demand, environmental volatility	QCA; qualitative data from 20 manufacturers	YES	YES

Note: See, for example, Ren and Zheng (2024) for a bibliometric analysis of the wider smart PSS literature.

architectures involving external partners may be designed (Heirati et al., 2024). Knowledge of the specific configurations provides insight into complementarity effects (i.e., how different factors reinforce each other) in generating smart PSS (Beverungen et al., 2019). Such knowledge is relevant because it can guide providers of smart PSS in i) developing new activity systems with external partners and ii) evaluating existing activity systems and redesigning them (if necessary).

2. Conceptual background

2.1. Perspectives on smart PSS

Existing empirical research on smart PSS covers two broad research strands (see Table 1 for an overview): smart PSS development and adoption (Bag et al., 2024; Dalenogare et al., 2023; Kohtamäki et al., 2025; Kropp and Totzek, 2020; Münch et al., 2022; Sassanelli and Pacheco, 2024; Wang et al., 2021) and smart PSS implementation (Dalenogare et al., 2022; Ferreira et al., 2022; Tseng et al., 2021).

Studies that fall into the first group indicate that the development and provision of smart PSS often involve collaborative ecosystems and the combination and orchestration of diverse sets of capabilities. For example, prior work reveals alternative forms of inter-firm collaboration within digital servitization ecosystems (i.e., expanded, enhanced, platform, and symbiotic business models), each characterized by unique approaches to value creation and capture in the context of smart PSS development (Dalenogare et al., 2023). In addition, based on an analysis of multiple business cases, Münch et al. (2022) identify 46 capabilities within the framework of socio-technical systems theory that are considered essential for the development and delivery of smart PSS. Prior work has also examined the role of artificial intelligence (AI) for smart PSS, offering a path model delineating ecosystem partnerships, AI-enabled PSS, and technologies conducive to the development of autonomous solutions (Kohtamäki et al., 2025). Furthermore, this case study offers managerial practices for evangelizing, strategizing, and routinizing AI-enabled PSS. A study by Bag et al. (2024) further shows that smart PSS capabilities are built through zero-level organizational capabilities and that smart circular PSS capabilities can pay off for firms in terms of improved financial and environmental performance. Studies in this research strand that adopt a more customer-centric view indicate that the adoption of smart PSS is influenced by institutional pressures as well as customer beliefs about quality and value of smart PSS. Specifically, the effects of different facets of institutional pressure on customer's intention to adopt smart PSSs are complex and context-dependent (Kropp and Totzek, 2020). While normative pressure was found to have a non-linear effect on adoption, mimetic pressure was shown to positively influence the adoption of customer input-oriented PSS, while its effect on customer output-oriented PSS was non-linear (Kropp and Totzek, 2020). In addition, prior work shows that the Internet of Things (IoT) can influence the perceived quality of smart PSS as well as customer involvement (Sassanelli and Pacheco, 2024).

Research on smart PSS that focuses on their implementation has provided insights into different issues and industries. For example, a study by Tseng et al. (2021) examined the implementation of smart PSS in the banking industry. Using a combination of fuzzy Delphi and fuzzy decision-making methods, the authors have developed a model to improve the operational performance of smart PSS in the banking sector. In addition, prior work has examined the integration of smart PSS within the context of automotive manufacturing, highlighting key factors for a successful implementation (Ferreira et al., 2022). Finally, Dalenogare et al. (2022) provide insights into the role of data integration in data-savvy service ecosystems, thereby advancing knowledge on multi-channel digital services delivery.

2.2. Theory and research model

The purpose of our research is to advance the smart PSS literature by

adopting an activity system perspective and using a configurational approach. While the activity system view on smart PSS has links to previous work on collaborative ecosystems (e.g., Dalenogare et al., 2023) and necessary capabilities for smart PSS (e.g., Münch et al., 2022), it can provide new insights into possible actor-activity arrangements through which manufacturers can address resource and capability requirements with external partners. It therefore enables us to make a substantive contribution that may complement the findings produced in previous research.

Activity system theory (Zott and Amit, 2010) contends that an activity involves the engagement of different resources (e.g., human, physical, technical and/or financial resources) to achieve an objective. Within our study, the activity system refers to the set of activities performed by a focal manufacturer and its external partners for the creation of smart PSS. Designing an activity system involves selecting relevant activities and connecting them. As such, the system reflects how a firm arranges, orchestrates, and utilizes (internal and external) resources to conduct activities and accomplish objectives. A central feature of an activity system is the possible interdependency between activities, which means that specific activities can intertwine and reinforce each other to maximize their intended outcome or output within a changing environment. In addition, the design of an activity system requires the identification of actors with sufficient resources and capabilities to perform the desired activities. Within this context, prior work has shown that effective resource mobilization from external partners plays a vital role for successful innovation processes and new product success (Thornton et al., 2019).

This study aims to explain the creation of valuable smart PSS by manufacturers and their network partners. We focus on parameters of an activity system that relate to its content and governance, as well as environmental factors that may influence an organizational activity system (Zott and Amit, 2010). More specifically, we focus on actor diversity and activity diversity as actionable parameters of a firm's activity system and customer demand and environmental volatility as environmental demands. Prior research on smart PSS reveals that manufacturers need to orchestrate their competencies and behaviors (Koldewey et al., 2022), and that actors other than the manufacturer can have important roles in building and implementing smart PSS (Sassanelli and Pacheco, 2024). For example, the management of data from different sources can create data integration challenges that have implications for digital service delivery. As a consequence, some manufacturers invest in network capabilities to build effective service ecosystems with external partners (Dalenogare et al., 2022).

Fig. 1 shows the research model of our study and uses a 4n-Venn diagram to symbolize the configuration approach underlying this research. In essence, the model suggests that a (limited) set of configurations of activity system parameters should lead to the creation of valuable smart PSS. This notion is backed up by configuration theory, which suggests that organizations are conceivable systems that are composed of elements whose interplay can generate a limited set of patterns leading to superior performance (Ketchen et al., 1997; Meyer et al., 1993). Configuration theory holds that particular outcomes are often not the result of single conditions but emerge from the synergy of multiple antecedents (Fiss, 2011; Misangyi et al., 2017).

Valuable smart PSS are complex and technologically advanced systems (e.g., Chen et al., 2020; Zheng et al., 2019) that are supposed to offer added value for customers (e.g., Beverungen et al., 2019; Chen et al., 2020). Value refers to the benefits delivered to customers through, for example, enhanced functionality, improved efficiency, and tailored customization. Delivering differential value for customers is at the heart of firms' digitalization strategies (Bharadwaj et al., 2013), and as such is also a key premise for the successful commercialization of smart PSS. To create value for customers, firms should effectively leverage capabilities, align them with customer perceptions, and claim a differential advantage (Kumar and Reinartz, 2016). By leveraging capabilities, firms use own resources and core competencies or those from external

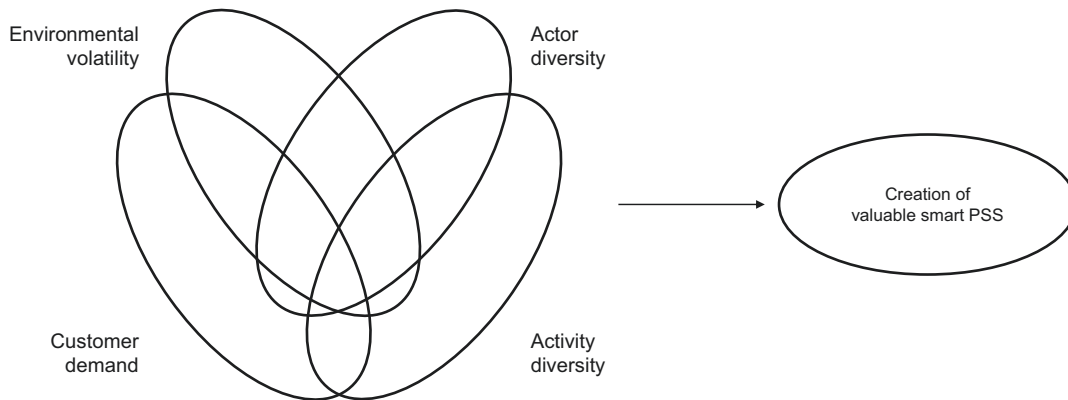


Fig. 1. Research model.

partners to deliver offerings that meet or even exceed customer expectations. Alignment with customer perceptions means that firms know their customers' wishes and what they look for in an offering, which requires a profound understanding of customers' needs and expectations. Claiming a differential advantage involves distinguishing a firm's offerings from competitors. Such strategic positioning involves the creation of unique selling propositions that distinguish a firm's products or services in the market.

Firms can facilitate and advance value creation by collaborating with external partners that possess critical resources and capabilities and that specialize in certain activities (e.g., Cui and O'Connor, 2012; Goerzen and Beamish, 2005). Smart PSS often involve the provision of services together with a product, which implies that an organization equipped (primarily) for production shifts to a more service-oriented business model (e.g., Kowalkowski et al., 2017). Such a transformation process may involve new activities and require collaboration with external partners (e.g., Heirati et al., 2024). For example, activities such as data handling and storage, customer interaction, predictive maintenance, etc. may be at least partially performed by external partners. Smart PSS providers have to decide what activity system will work for them, which involves decisions regarding the activities that are required to create valuable smart PSS as well as the actors that perform these activities. While some manufacturers prefer to work with generalists (i.e., external partners that offer a wide range of activities), others prefer to work with specialists (i.e., external partners that specialize in specific activities). Thus, a manufacturer's activity system for the creation of valuable smart PSS can be characterized in terms of *actor diversity* and *activity diversity*-concepts that have also been highlighted as critical antecedents of firm performance in the alliance management and the network management literatures (e.g., Goerzen and Beamish, 2005; Jiang et al., 2010). While actor diversity refers to the diversity of partners with whom a manufacturer collaborates, activity diversity refers to the diversity of activities (or functions) as performed in an activity system. High actor diversity implies that a manufacturer collaborates with a wide range of external partners that differ in terms of their characteristics and/or the resources that they contribute. High actor diversity can bring access to an enriched pool of necessary inputs, but it can also increase complexity and coordination costs (Jiang et al., 2010). High activity diversity implies functional heterogeneity, which increases with the degree to which actors in an activity system do not share common activities (Cui and O'Connor, 2012). Activity systems with low activity diversity (and many actors) may suffer from activity redundancy and provide opportunities for efficiency gains.

Since the environment of a firm's activity system is subject to change (Zott and Amit, 2010), environmental demands may influence the constellations of actors and activities to successfully develop and commercialize new offerings (e.g., Achrol and Stern, 1988; Siggelkow, 2001). Therefore, we consider two environmental factors as

confounding conditions in our model. *Expected customer demand* is defined as the estimated demand after an offering in the market (Wieseke et al., 2008), and involves the dimensions market existence and demand after smart PSS. A growing market and heterogenous customer preferences may lead to more scalable or complex smart PSS, which may require involvement of diverse actors contributing different functions. Thus, the nature of expected customer demand should influence the way in which firms configure activity systems. In addition, we consider *environmental volatility* to account for changes and dynamism in industry environments. Environmental volatility is multi-dimensional concept reflected by change of product/service technology, change of customer preferences, and market changes (Antia and Frazier, 2001). Volatile environments may foster firms to develop more resilient activity systems to cope with frequent changes in customer preferences or technological turbulence. In addition, a volatile environment requires firms (and especially smart PSS providers) to monitor and adapt to environmental changes in order to avoid misalignment of activities (Hohmann and Posselt, 2019). Table 2 provides an overview of the conditions (and their dimensions).

The interplay of actor diversity, activity diversity, customer expectations and environmental volatility may affect the way in which a manufacturer will generate valuable smart PSS. A collaborative approach with a diverse range of actors and the consideration of multiple functions within the manufacturer's ecosystem could facilitate the

Table 2
Overview of focal conditions and their dimensions.

Conditions	Dimensions	References
<i>Activity system antecedent conditions</i>		
Actor diversity	One-dimensional: variety of external factors involved in providing the smart PSS	Cui and O'Connor (2012); Goerzen and Beamish (2005)
Activity diversity	One-dimensional: variety of activities performed by external actors	Cui and O'Connor (2012)
<i>Environmental antecedent conditions</i>		
Expected customer demand	Two-dimensional: - customer demand for smart PSS - market for smart PSS	Wieseke et al. (2008)
Environmental volatility	Three-dimensional: - changes in customer preferences - changes in product/service technology - evolution of new developments	Antia and Frazier (2001)
<i>Outcome condition</i>		
Creation of valuable smart PSS	Three-dimensional: - leveraging own capabilities - aligning with customer perception - claiming differential advantage	Kumar and Reinartz (2016)

interoperability of products and services in a smart PSS. It would enable the leveraging of a diverse set of resources and capabilities, thereby promoting differential value and flexibility in responding to diverse customer needs (Bharadwaj et al., 2013). Furthermore, it would facilitate the adaptation of smart PSS to different contexts and meet the demand for complex service applications (Grover and Kohli, 2013). In order to develop complex offerings, such as smart PSS, it is vital for firms to consider not only the ecosystem but also the integration of the customer (Pagani, 2013). Consideration of customer expectations and environmental volatility helps firms to anticipate market shifts and draw conclusions regarding the potential redesign of the activity system (Sassanelli and Pacheco, 2024). Hence, actor diversity, activity diversity, expected customer demand and environmental volatility may reinforce each other and fall into a (limited) set of configurations that are sufficient for valuable smart PSS.

3. Research design

3.1. Data collection

We conducted a multi-case study (Eisenhardt, 1989) as part of a major project on smart PSS to better understand how manufacturing firms configure their activity system to create valuable smart PSS for customers (Papert et al., 2023). We focused on manufacturers in the equipment and machinery industries and conducted in-depth interviews with executives from different firms. The manufacturers offer a wide range of products, such as heating systems, packaging machinery, compressors, power tools, robots, and industrial gas systems. All manufacturers are based in European countries, serve international markets, and have several years of experience with smart PSS. Their number of employees ranges from 200 to 430,000 and their turnover ranges from 70 million and 90 billion euros (as of 2023).

Data collection took place over a period of approximately ten months during 2019/20, from the initial contact preparations to the in-depth interviews. Prior to the interviews, 15 interview partners were contacted via telephone. These telephone calls provided contextual information about the firm and its smart PSS offering. The calls generated 28 pages of summary notes and contextual information, forming the basis for subsequent interviews. Five participants received the interview guide via email, along with a description of the study. The preliminary telephone conversations proved valuable; in three cases, the background information about the study helped establish contact with more suitable experts within the firms. Throughout the study, expert selection was based on identifying individuals with several years of experience implementing smart PSS.

We conducted 20 in-depth interviews. These interviews were conducted at the respective workplaces of the interview partners. The qualitative data obtained from the interviews was supplemented by observational data collected during site visits to the firms, as well as archival data collected from corporate websites and annual reports. The interviewees hold senior positions within the firms, such as Senior VP Advanced Services, Head of Service Product Management, Digital Innovation Manager, and Head of Product Strategy, and they have a comprehensive understanding of smart PSS. Appendix A1 provides an overview of the interview partners. To structure the interviews and obtain detailed insights, we used a semi-structured interview guide. The interview guide consisted of an introductory section that provided a brief explanation of the topic. This was followed by segments dedicated to smart PSS offerings and elements of the activity system. An additional printed presentation was used during the interviews to facilitate the conversation. The presentation included a brief explanation of smart PSS, accompanied by illustrative examples. At the end of each interview, interviewees had the opportunity to provide additional information or ask questions. The average interview length was 81 min. In total, the interviews lasted 26 h and 53 min. All interviews were audio-recorded and then transcribed for subsequent analysis. The transcript consisted

of 410 pages.

In addition to the interview guide, we used further data sources to enhance our understanding of the subject matter and validate the information obtained through the interviews. Specifically, we used publicly accessible data about the firms, as well as insights from preliminary telephone conversations, where applicable. During three of the interviews, the interview partners gave a presentation that further explained their smart PSS. Additionally, five company tours were conducted to improve understanding of the firms' smart PSS. Prior to one interview, an interview partner gave a presentation at a competence center session on business models in the digital world. These data sources were used to prepare for the interview and enhance comprehension and validation of the comments and remarks made by the interview partners (data triangulation). Appendix A2 provides an overview of the data sources used in this study.

3.2. Data analysis

We used fsQCA to analyze the data (Ragin, 2008). FsQCA is a set-theoretic method that helps to uncover configurations of conditions that lead to an outcome. For a fsQCA, the antecedent conditions and the outcome condition under study need to be represented as fuzzy sets, which means that each case's membership in the sets of conditions needs to be determined. Fuzzy-set scores range from 0 to 1, whereby 0 means that a case is fully out of a fuzzy set and 1 means that a case is fully in a fuzzy set (Ragin, 2008). A score of 0.5 denotes the crossover point, which means that a case is neither in nor out of a fuzzy set.

To obtain the fuzzy-set membership scores for each empirical case, we followed the guidelines in the QCA literature (Basurto and Speer, 2012; Nishant and Ravishankar, 2020; Schneider and Wagemann, 2010) and employed the Generic Membership Evaluation Template (GMET; Tóth et al., 2017). Using GMETs ensures a structured and systematic approach to converting qualitative data into fuzzy-set membership scores for further analysis. GMETs take into account the dimensions of conditions and allow for nuanced interpretation of qualitative data. A GMET comprises several sections, including an overall case description followed by a detailed breakdown of relevant dimensions for each condition (Tóth et al., 2017). These dimensions are evaluated in relation to their effect (positive or negative) on set membership. This facilitates assigning a fuzzy-set membership score to a particular case. To support the evaluation of the dimensions and ensure transparent calibration, a GMET incorporates illustrative quotes from the interviews. Appendix A3 shows the GMETs for cases A and B, considering the outcome and antecedent conditions. Insights from interview transcripts, presentations, background information, and phone calls were integrated to generate the GMETs. Using GMETs ensures rigor in calibrating qualitative data and avoids oversimplifying the analysis of rich, complex qualitative material. In total, we generated 100 GMETs for each of the 20 cases.

In our study, we defined 6-value fuzzy sets (with fuzzy-set scores of 0, 0.2, 0.4, 0.6, 0.8, and 1) to avoid potential ambiguity issues regarding case membership (i.e., cases that meet the crossover point of exactly 0.5). For actor diversity, we examined (two-digit) SIC (Standard Industrial Classification; e.g., Kettinger et al., 1994) codes to obtain insight of the different actors a firm is working with. SIC represent industry categories that provide a meaningful and objective representation when assessing external partners (e.g., Cui and O'Connor, 2012; Goerzen and Beamish, 2005). To ensure comparability across all cases, we tallied the total number of unique SIC codes and then standardized the sum by dividing it by the total number of external partners involved in each case. For activity diversity, we examined the activities performed by the external partners in each case. When two partners do not engage in any overlapping activities, they were assigned a score of 1, and 0 otherwise. This approach aligns with the conceptualization of activity diversity (e.g., Cui and O'Connor, 2012). To ensure comparability across the cases, the allocated score was normalized by the number of comparisons per

case. We added a constant of 0.001 to avoid fuzzy-set scores of exactly 0.5 and prevent problems when with regard to a case's membership in a set (Fiss, 2011). We used plausibility assessments to arrange the data and specify the fuzzy-set membership scores (Basurto and Speer, 2012). In case of discrepancies, we discussed and reviewed the assignments made and examined supporting data (if available) before reassessing the templates.

We used the fs/QCA software (Ragin and Davey, 2022) to analyze the data and considered the recommendations made in the QCA literature (e.g., Greckhamer et al., 2018). First, we constructed a truth table that captures all logically possible combinations of the antecedent conditions as well as the number of cases that indicate these combinations. In line with the recommendations in the literature, we assessed frequency and consistency thresholds to refine the truth table (Ragin, 2008; Schneider and Wagemann, 2010). Given the sample size of 20, we set the frequency threshold at 1. This threshold ensured that all configurations with empirical representation are part of the analysis and that configurations without empirical representation are treated as logical remainders in the analysis. Next, we examined consistency scores to determine what configurations are consistently sufficient pathways to achieve the outcome under study. We set the consistency threshold at value 0.9, which exceeds the commonly used threshold score of 0.8 and is thus more conservative. Finally, we inspected proportional reduction in inconsistency (PRI) scores and set the threshold at value 0.71 (Misangyi and Acharya, 2014). Appendix A4 shows the refined truth table used for the analysis.

We used the Quine-McCluskey algorithm, as implemented in the fs/QCA software program (Ragin and Davey, 2022), to identify the configurations that are minimally sufficient for creating valuable smart PSS. The results show the parsimonious and intermediate solutions obtained by the analysis, which help distinguish core and peripheral conditions within configurations for the outcome (Fiss, 2011). A core condition, present in both the parsimonious and intermediate solutions, is considered causally essential. A peripheral condition, found only in the intermediate solution, is considered a surrounding condition.

3.3. Results

Table 3 summarizes the results of the analysis using the notation of Ragin and Fiss (2008) and shows two configurations for the creation of valuable smart PSS based on the parsimonious and the intermediate solutions obtained by the analysis. In addition, Table 3 reports the overall solution consistency and overall solution coverage, as well as the

Table 3
Results of the fsQCA.

Antecedent conditions	Configurations	
	1	2
Actor diversity	●	●
Activity diversity	●	●
Environmental volatility	●	
Expected customer demand		●
Consistency	0.872	0.948
Raw coverage	0.714	0.835
Unique coverage	0.026	0.147
Overall solution consistency	0.878	
Overall solution coverage	0.861	

Notes: Intermediate and parsimonious solutions based on Quine-McCluskey algorithm; consistency threshold = 0.9; PRI threshold = 0.71; frequency threshold = 1 (100% of the cases); a full circle indicates the existence of a condition; a blank space denotes a subordinate condition; a large circle indicates a core condition; a small circle indicates a peripheral condition.

consistency, raw and unique coverage scores for the specific configuration. In an analysis of sufficiency, consistency indicates to what extent the cases show a perfect subset relation, and coverage indicates what proportion of the outcome is covered by a configuration, which helps assess empirical relevance (Ragin, 2008). The overall solution consistency score is 0.878 and the overall solution coverage score is 0.861. These scores suggest that the overall solution closely approximates a perfect subset relation, and that a substantial proportion of the outcome set is covered by the two configurations. For the specific configurations, Table 3 shows consistency, raw and unique coverage scores (Ragin, 2008). While raw coverage shows what proportion of the outcome is covered by a particular configuration, unique coverage partition what proportion of an outcome is exclusively covered by a particular configuration (Ragin, 2008; Schneider and Wagemann, 2010).

Configuration 1 combines the presence of actor diversity and activity diversity with environmental volatility. Environmental volatility is a core condition in this configuration and expected customer demand has a subordinate role. Configuration 1 suggests that manufacturing firms operating in a volatile environment can create valuable smart PSS when they design an activity system that involves diverse partners which perform different activities. Configuration 2 combines the presence of actor diversity and activity diversity with expected customer demand. Expected customer demand is a core condition in this configuration and environmental volatility as a subordinate role. Configuration 2 suggests that manufacturing firms with a profound understanding of markets and customer demand and an activity system that involves diverse partners that perform various activities can create valuable smart PSS. Of the two configurations, configuration 2 achieves higher coverage scores, which suggests that this solution has a higher empirical relevance.

3.4. Post hoc analyses

A comparison of the solutions indicates that both configurations include the presence of actor diversity and activity diversity, and that they differ with regard to the environmental conditions. We conducted a series of post hoc analyses to obtain further insights and test the robustness of the findings. In particular, we conducted 1) an analysis of necessity to further examine if actor diversity and activity diversity are essential for valuable smart PSS, 2) a sufficiency analysis using the same conditions and the same thresholds as before, but a more conservative PRI threshold (i.e., value 0.9) to test the robustness of findings, and 3) another sufficiency analysis for the negation of the outcome (i.e., ~ creation of valuable smart PSS) to obtain additional insight into the causal logic between the antecedent conditions and the outcome condition.

The results of a necessity analysis show that actor diversity (necessity consistency = 0.939, necessity coverage = 0.707) and activity diversity (necessity consistency = 0.968, necessity coverage = 0.696) are conceivable as necessary conditions for valuable smart PSS for the studied firms in the equipment and machinery industry as the results exceed the commonly used necessity consistency threshold of 0.9 (Ragin, 2006). Inspection of the necessity coverage scores further indicates that the two necessary conditions are nontrivial (Ragin, 2006), but insufficient to bring about valuable smart PSS on their own.

The sufficiency analysis with the same thresholds as before, but a more conservative PRI threshold (i.e., value 0.9) reveals one configuration. This configuration shows the same composition and the same consistency and coverage scores as configuration 2 from the previous analysis.

To assess causal asymmetry, we planned to conduct a sufficiency analysis for the negation of the outcome. As in the previous sufficiency analyses, we constructed a truth table and defined frequency, consistency, and PRI thresholds to simplify the truth table for subsequent analysis. However, inspection of the PRI scores revealed values below 0.6, which are below the commonly used thresholds mentioned in the QCA literature. Therefore, we did not proceed with the sufficiency

analysis for the negation of the outcome.

3.5. Typical case analysis

Having examined the robustness of the findings, we analyzed typical cases, that is, cases with membership in the outcome set, as well as the configuration sets obtained by the (main) analysis. Typical cases score high on both configurations of antecedent conditions for an outcome and the outcome condition. To identify these cases, we developed macro-variables and joined the antecedent conditions that form a configuration using the logical operator “and.” Next, we examined the fuzzy-set membership scores of all the empirical cases in the outcome set and the configuration sets. We set the fuzzy-set membership threshold score for a case to be selected as a typical case at higher than 0.5, which means that a case is more in than out of a respective set. Next, we examined each of these typical cases in more detail to gain additional insight into the specific activities and actor constellations used by the companies and to further strengthen our theorizing. Table 4 provides an overview of the typical cases identified by the analysis.

Inspection of Table 4 reveals that all cases (i.e., for configuration 1 and 2) involve a wide range of actors that together cover a broad set of activities for generating smart PSS. For example, the results show that case A (printing press manufacturing) involves actors such as the customer/user, a consulting company, a financial expert, a telematics provider, a platform operator, a legal expert and compliance auditor, a security auditor, and an insurance company.

A comparison of actors across the typical cases for configuration 1 indicates that all three cases involve customers/users, telematic providers, platform operators, legal/compliance experts, and financial, insurance or risk-related experts, and security auditors. In addition, the analysis of activities performed by the actors involved in generating smart PSS shows that some activities are performed by multiple actors, while some are executed by specific ones. For example, multiple actors (i.e., customers/users, telematics providers, platform operators, insurance companies, and data scientists) participate in generating, transmitting, curating, or analyzing data. In addition, several actors perform activities related to generating IT and data infrastructures (i.e., telematics providers, platform operators, system integrators, consulting companies) or help address legal, regulatory and security issues (i.e., legal experts and compliance auditors, security auditors, insurance companies, and financial experts). The finding that the case companies involve multiple actors who share activities further details the findings of the configuration analysis. Redundancy in an actor-activity system enables the case companies to validate inputs received from different actors and to mitigate risks.

For configuration 2, a comparison of actors across the three typical cases indicates that the common set of actors includes telematics providers, platform operators, legal experts and compliance auditors. Furthermore, the cases P and R also show the involvement of a consulting company, while the cases P and S show the involvement of an insurance company. The results further reveal that, as for the case companies in configuration 1, multiple actors involved in generating smart PSS perform similar activities that center around issues such as generating, transmitting, curating, or analyzing data; generating IT and data infrastructure; and addressing legal, regulatory and security issues. For the cases in configuration 2, an additional activity theme for the involved actors is the evaluation of risks and the development of financial models, which is provided by insurance and consulting companies, as well as spin-offs.

Common to both groups of typical cases is the participation of telematics providers and platform operators (i.e., actors that perform activities central to generating smart PSS). While the cases in configuration 1 collaborate with customers/users, this is not always the situation for the cases in configuration 2. However, the cases in configuration 2 rely on legal experts and compliance auditors, which appear only twice in the actor-activity constellations of cases in

Table 4
Typical cases.

Cases	Industry focus	Actors	Activities
<i>Typical cases for configuration 1</i>			
A	Printing press manufacturing	Customer/user	<ul style="list-style-type: none"> – Utilization of smart PSS without acquiring ownership to increase overall equipment effectiveness – Contribution to the definition of usage agreement with smart PSS provider (partnership) regarding data sovereignty and access – Provision of relevant data to the smart PSS provider – Service feedback to the smart PSS provider
		Consulting company	<ul style="list-style-type: none"> – Provision of individual consumer insights to enhance smart PSS performance – Establishment of a cloud-based database to derive specific performance parameters for smart PSS utilization
		Financial expert	<ul style="list-style-type: none"> – Exploration of diverse financing methods for the scaling phase – Development of an operational financing model for smart PSS subscriptions
		Telematics provider	<ul style="list-style-type: none"> – Construction of a communication infrastructure connecting the consumer-side smart PSS and the provider – Management of access control to the smart PSS – Provision of relevant data for smart PSS analytics
		Platform operator	<ul style="list-style-type: none"> – Provision of a platform infrastructure for the implementation of a big data platform – Realization of data storage and warehousing solutions – Execution of standard and big data analytics on smart PSS data
		Legal expert and compliance auditor	<ul style="list-style-type: none"> – Preparation of documentation concerning the safety and reliability of the smart PSS – Provision of country-specific regulatory guidance for the design of the technological smart PSS architecture – Provision of country-specific regulatory guidance for drafting smart PSS usage agreements regarding data sovereignty, access, and depreciation
		Security auditor	<ul style="list-style-type: none"> – Preparation of documentation concerning the safety and reliability of the smart PSS – Auditing of adherence to guidelines regarding the safe operation of the smart PSS

(continued on next page)

Table 4 (continued)

Cases	Industry focus	Actors	Activities
C	Industrial gas systems	Insurance company	<ul style="list-style-type: none"> – Analysis of provided smart PSS data for damage detection – Provision of insurance services and premiums based on smart PSS data
		Customer/user	<ul style="list-style-type: none"> – Participation in workshops to unmask customer requirements for smart PSS – Participation in the development of a smart PSS architecture – Participation in a pilot phase for the realization of a customized smart PSS
		Data scientist	<ul style="list-style-type: none"> – Execution of analytics based on smart PSS data
		Telematics provider	<ul style="list-style-type: none"> – Development and deployment of sensor systems and communication technologies for smart PSS data collection – Transmission of smart PSS data to an analysis center
		Platform operator	<ul style="list-style-type: none"> – Provision of an infrastructure for the implementation of a cloud platform – Configuration of the platform infrastructure for smart PSS data analytics
		Legal expert and compliance auditor	<ul style="list-style-type: none"> – Provision of guidance regarding national data sovereignty and security regulations for smart PSS data exchange – Provision of guidance regarding the smart PSS usage agreement, including intellectual property and liability
		System integrator	<ul style="list-style-type: none"> – Development of a technical architecture for a smart PSS – Rollout and implementation of the technical architecture for a smart PSS
		Customer/user	<ul style="list-style-type: none"> – Participation in the development of a smart PSS solution, including its operation, control, security requirements, and design specifications – Participation in piloting the realization of a customized and market-ready smart PSS – Contribution to the development of future generations of smart PSS
		Telematics provider	<ul style="list-style-type: none"> – Construction of a communication infrastructure connecting the consumer-side smart PSS and the provider – Deployment of sensor systems for the collection of and access to permissible smart PSS utilization data
		Platform operator	<ul style="list-style-type: none"> – Realization of a cloud-based data platform for

Table 4 (continued)

Cases	Industry focus	Actors	Activities
P	Typical cases for configuration 2 HVAC systems (Heating, Ventilation & Air Conditioning)	Financial expert	<ul style="list-style-type: none"> – data aggregation and structuring – Configuration of the data platform for decentralized smart PSS analytics and management – Identification of national legal and user-related security requirements – Access to and analysis of permissible smart PSS data (utilization behavior) for operational damage assessment – Development of an operational financing model for smart PSS usage agreements
		Security auditor	<ul style="list-style-type: none"> – Identification of user-related security requirements and design specifications – Auditing of adherence to the requirements and specifications regarding smart PSS utilization
		Insurance company	<ul style="list-style-type: none"> – Access and analysis of smart PSS data for damage and risk evaluation – Provision of insurance services based on smart PSS specific risks and utilization – Development of an operational financing model for smart PSS usage agreement
		System integrator	<ul style="list-style-type: none"> – Development of an IT solution for smart PSS operations
		Spin-off	<ul style="list-style-type: none"> – Development of a business model, including an operational financing model for smart PSS usage agreements – Distribution of smart PSS – External and internal marketing of smart PSS
		Consulting company	<ul style="list-style-type: none"> – Development of an operational financing model for smart PSS usage agreements – Provision of guidance regarding smart PSS risk evaluation – Provision of country-specific legal guidance for drafting smart PSS usage agreements – Provision of guidance for the utilization of public funding
		Telematics provider	<ul style="list-style-type: none"> – Construction of a physical communication infrastructure connecting the consumer-side smart PSS and the provider – Development and deployment of sensor systems and communication technologies for smart PSS data collection – Access to and analysis of permissible smart PSS data
		Platform operator	<ul style="list-style-type: none"> – Realization of a cloud-based data platform for
		Customer/user	<ul style="list-style-type: none"> – Participation in the development of a smart PSS solution, including its operation, control, security requirements, and design specifications – Participation in piloting the realization of a customized and market-ready smart PSS – Contribution to the development of future generations of smart PSS
		Telematics provider	<ul style="list-style-type: none"> – Construction of a communication infrastructure connecting the consumer-side smart PSS and the provider – Deployment of sensor systems for the collection of and access to permissible smart PSS utilization data

(continued on next page)

Table 4 (continued)

Cases	Industry focus	Actors	Activities		
R	Textile machinery manufacturing/spinning machinery	Platform operator	<ul style="list-style-type: none"> to enable updates, control, and risk evaluation – Provision of a platform architecture to connect consumers and relevant stakeholders involved in the smart PSS usage agreement 		
		Legal expert and compliance auditor	<ul style="list-style-type: none"> – Provision of country-specific legal guidance for drafting smart PSS usage agreements, specifically addressing warranty and liability regulations 		
		Insurance company	<ul style="list-style-type: none"> – Access and analysis of permissible smart PSS data regarding deployment for risk evaluation – Consideration of and compliance with country-specific legal regulations, including warranty and liability – Provision of insurance services based on smart PSS specific risks, usage agreement, and stakeholders involved 		
		Data scientist	<ul style="list-style-type: none"> – Provision of artificial intelligence algorithms – Execution of analytics based on smart PSS data 		
		Consulting company	<ul style="list-style-type: none"> – Provision of guidance regarding operational financing models and accounting for smart PSS usage agreements – Provision of guidance regarding the definition of the smart PSS value proposition 		
		Telematics provider	<ul style="list-style-type: none"> – Construction of a physical and high-performance communication infrastructure connecting the consumer-side smart PSS and the provider – Deployment of sensor systems for the collection of and access to smart PSS data – Preprocessing of large volumes of collected smart PSS data for transmission – Development of communication standards 		
		Platform operator	<ul style="list-style-type: none"> – Provision of a cloud-based platform infrastructure – Configuration of the platform infrastructure for the implementation of smart PSS micro-services – Realization of data storage solutions 		
		Legal expert and compliance auditor	<ul style="list-style-type: none"> – Provision of country-specific guidance on compliance, data sovereignty, and data access – Support and audits for ensuring compliance with country-specific regulations 		
		S	Power tool manufacturing	Telematics provider	<ul style="list-style-type: none"> – Provision of hardware solutions to connect the consumer-side smart PSS to the provider's services

Table 4 (continued)

Cases	Industry focus	Actors	Activities
		Platform operator	<ul style="list-style-type: none"> – Provision of a cloud-based platform infrastructure and consideration of legal security requirements – Configuration of the platform infrastructure for the implementation of smart PSS microservices
		Legal expert and compliance auditor	<ul style="list-style-type: none"> – Provision of guidance regarding national regulations for secure smart PSS utilization
		Security auditor	<ul style="list-style-type: none"> – Assurance of cloud infrastructure and smart PSS compliance with legal security requirements
		Insurance company	<ul style="list-style-type: none"> – Provision of insurance services for smart PSS – Financial coverage of maintenance services for smart PSS

configuration 1. These differences are due to the different environmental conditions in which the case companies operate (here reflected by environmental volatility and expected customer demand). While environmental volatility is part of configuration 1, expected customer demand is part of configuration 2 of the configuration analysis. Firms operating in a volatile environment involve customers/users intensively, while the other group of companies emphasizes translating customer demands into compliance and regulatory assurance.

In summary, the cumulative findings obtained by the analysis provide more detailed insights into specific actors and activities that the case companies use to create valuable smart PSS, thus offering a more nuanced and fine-grained understanding of actor-activity constellations for the generation of smart PSS.

4. Discussion

4.1. Theoretical contributions

The purpose of this study is to provide insight into the creation of valuable smart PSS from an activity perspective. Specifically, this study aims to advance the knowledge on how manufacturers configure activity systems with external partners to generate smart PSS. The results of our analysis make three major contributions to the literature.

Drawing on activity system theory (Zott and Amit, 2010), we illuminate important parameters of an activity system (i.e., actor diversity and activity diversity) and examine their interplay with environmental factors (i.e., expected customer demand and environmental volatility) to achieve valuable smart PSS. Thus, our research integrates the smart PSS and the activity system literatures and provides a more nuanced understanding of activity system profiles for achieving novel technological solutions. Knowledge of such profiles is important as they may produce a number of beneficial effects (e.g., access to resources), but also come with challenges for organizations (e.g., complexity). The integrative view adopted in our study adds to prior research on (value) co-creation and ecosystems in the context of smart PSS (e.g., Sassanelli and Pacheco, 2024).

The results of our study corroborate those of prior research (e.g., Beverungen et al., 2019; Hohmann and Posselt, 2019) by indicating that manufacturers should take into account customer demands and collaborate with external actors to expand their functional resource base for creating valuable smart PSS. Our results suggest that diverse (eco-)systems allow manufacturers to generate differential value with smart PSS. In addition, the configurations obtained by the analysis extend the extant knowledge. Specifically, they indicate that high actor and activity

diversity in combination with different environmental demands lead to valuable smart PSS. Thus, comprehensive activity systems, in which external partners have different roles and perform heterogeneous functions may help firms to generate valuable smart PSS in the presence of growing markets and environmental changes in the equipment and machinery industry. Knowledge of these configurations and the additional insights into particular actor-activity constellations used by typical cases for each configuration contributes to a more nuanced understanding of how manufacturers can bring about attractive market offerings and adds to the smart PSS literature (e.g., Dalenogare et al., 2022; Li et al., 2024; Valencia et al., 2015; Zheng et al., 2019).

The two configurations also offer insight into complementary effects between the antecedent conditions. The presence of both actor diversity and activity diversity in combination with expected customer demand or environmental volatility suggests reinforcing effects. Manufacturers that work together with different external partners and an activity system that shows functional heterogeneity may diversify risks and achieve resilience. Hence, manufacturers are in a better position to cope with varying environmental demands as well as balance varying levels of performance as shown by their external partners. In addition, a comprehensive activity system allows manufacturers to access an enriched resource pool (Jiang et al., 2010), address diverse customer demands, and transform them into market offerings that provide superior customer value.

A potential explanation for these findings is that manufacturers lack the required resources and capabilities to generate smart PSS in-house. They thus require external expertise and resources, especially in the presence of frequently changing environments, and high customer demands. This knowledge contributes to the servitization literature, which reveals that manufacturers may opt for different organization architectures for successful servitization (Heirati et al., 2024). Here, the results of our analysis provide a more detailed understanding of how organizational architectures involving external partners can be designed.

4.2. Managerial implications

From a managerial point of view, the configurations obtained by the analysis may serve as templates for designing new activity systems to generate smart PSS or to assess existing ones and identify opportunities for reconfigurations. Integrating diverse expertise and resources can enhance the creation of smart PSS, especially in the equipment and machinery industry. Thus, identifying and evaluating appropriate external partnering opportunities and taking preemptive action in establishing relationships with diverse external partners can pay off in the long run. Thus, manufacturers should invest in alliance management capabilities (e.g., Leischnig et al., 2014; Schilke and Goerzen, 2010) and leverage them to build effective activity systems for smart PSS. The insights of the analysis of typical cases may guide manufacturers in evaluating particular partnering opportunities and in negotiating relevant activity repertoires.

The search for external expertise outside of the comfort zone of the familiar technical domain may force manufacturers to soften existing boundaries, make compromises regarding institutional logics, and accept less control over processes. Thus, building a comprehensive activity system with diverse partners can create new challenges and risks to be addressed. High interaction quality and seamless exchanges of resources, knowledge or data may become more challenging between actors that differ in their characteristics and core competencies. Hence, firms should develop clear transparency strategies (Granados and Gupta, 2013) and appropriate governance mechanisms for a controlled opening and communication, and, at the same time, mechanisms for defending one's own competencies to prevent excessive system visibility and eventual vulnerability (Grover and Kohli, 2013).

Collaboration of diverse actors that perform heterogeneous functions may produce complexity and increase coordination costs. Thus, the orchestration of resource mobilization to ensure that all partners

contribute the necessary inputs in a timely and adequate manner becomes increasingly important (e.g., Thornton et al., 2019). This requires that collaborating firms (at least partially) align processes and systems to establish a sufficient degree of organizational compatibility, or consider the inclusion of ecosystem integrators to coordinate the activities of the collaborating firms.

Finally, the configurations obtained by the analysis may serve as benchmarks for the assessment of already existing activity systems and provide guidance for firms that wish to generate valuable smart PSS. Manufacturers may evaluate the existing activity system and identify opportunities for reconfiguration based on the results of this study. In addition, technology-driven roadmaps and maturity models should be further developed and expanded to include network components that capture both technical and (inter-)organizational elements for effective collaboration.

4.3. Limitations and avenues for further research

Our analysis is based on a qualitative study of manufacturers in the equipment and machinery industries. This limits the generalizability of our results to other industries. To further generalize the findings obtained by this study, future research should focus on other industries to develop a more complete picture of activity systems and the creation of smart PSS. For example, some industries are characterized by unique regulatory dynamics (e.g., life sciences and healthcare), while others have a stronger focus on consumers rather than business clients as customers. Future research should consider such contextual factors and examine their interplay with activity system parameters.

In addition, this research was conducted from the viewpoint of smart PSS providers, thus excluding the customer's viewpoint. Incorporating customer perspectives, however, could provide additional insights. Taking into account that our findings highlight collaboration with diverse actors, further research could investigate the establishment of governance with external actors for smart PSS. The challenges of data sovereignty, national/international data exchange, and legal requirements are of particular concern to smart PSS providers and could provide an avenue for further research on the topic.

Our study examined activity diversity and actor diversity as actionable parameters of a firm's activity system. While this approach contributes to middle-range theorizing on the creation of smart PSS, it may preclude more granular insights into the configurations of specific activities or actors involved in developing smart PSS. Future studies could address this issue by further illuminating and investigating such constellations to provide insight into activity and/or actor patterns and their orchestrating themes.

Finally, future research may conduct quantitative studies to further advance the understanding of activity systems for smart PSS and compare the robustness of the results of the fsQCA with variance-based methods of data analysis. In addition, longitudinal studies could examine the temporal stability of configurations over time. Such research would provide a deeper understanding of the events or incidents that lead to changes in the patterning of factors. Furthermore, longitudinal studies that account for activity system dynamics may investigate the evolution of actor roles throughout a collaboration or across the lifecycle of a smart PSS.

CRediT authorship contribution statement

Isabel Fischer: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Marcel Papert:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Alexander Leischnig:** Writing – review & editing, Writing – original draft, Conceptualization. **Günter Prockl:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of competing interest

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Appendix A. Supplementary data

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Data availability

The data that has been used is confidential.

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Isabel Fischer is PhD student at the Department of Supply Chain Management at the University of Bamberg, Germany. Her research interests are in the fields of digital transformation, servitization and smart product-service systems, and supply chain

management. Her research has appeared in various outlets including the Proceedings of the International Conference on Information Systems (ICIS) and the Hawaii International Conference on System Sciences (HICSS) among others.

Dr. Marcel Papert is Post doc at the Department of Supply Chain Management at the University of Bamberg, Germany. His research interests are in the fields of digital transformation and Internet of Things technologies, servitization, ecosystems, supply chain management, and circular economy. His research has appeared in various journals including Electronic Markets and the International Journal of Physical Distribution & Logistics Management as well as the Proceedings of the International Conference on Information Systems (ICIS) and the Hawaii International Conference on System Sciences (HICSS) among others.

Professor Alexander Leischnig holds the Chair of Business-to-Business Marketing at the Technische Universität Bergakademie Freiberg, Germany. His research interests include customer management, sales management, alliance management, and business digitalization. His work has been published in journals such as International Journal of Operations and Production Management, Journal of Business Research, Journal of Product Innovation Management, Journal of Service Research, and Technological Forecasting and Social Change among others.

Dr. Günter Prockl is Associate Professor at the Department of Digitalization at Copenhagen Business School, Denmark. He is also affiliated with the Faculty of Business Administration, Prague University of Economics and Business VŠE, W. Churchill Sq. 1938/4, 130 67 Prague 3, Czech Republic. His research interests include Supply Chain Management, Digitalization, Logistics Services, Business Ecosystems. His work has appeared in journals such as Journal of Supply Chain Management, Journal of Business Logistics, International Journal of Physical Distribution and Logistics Management, Electronic Markets, Computers in Industry and Journal of Transport Geography among others.