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Inter-firm collaboration and data integration for Smart Product-Service Systems: towards a digital servitization ecosystem

Lucas Santos Dalenogare

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THÈSE

Pour obtenir le grade de

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Thèse dirigée par **Marie-Anne LE DAIN** et **Alejandro GERMAN FRANK**

préparée au sein des **Laboratoires G-SCOP et LOPP**
dans les **Écoles Doctorales IMEP-2 et Escola de Engenharia**

Collaboration interentreprises et intégration des données pour les Systèmes intelligents de Produits-Services : vers un écosystème de la servicisation digitale

Jury :

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THESIS

For the title of

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Presented by

Lucas Santos Dalenogare

Thesis directed by **Marie-Anne Le Dain** and **Alejandro Germán Frank**

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Inter-firm collaboration and data integration for Smart Product- Service Systems: towards a digital servitization ecosystem

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ABSTRACT

Product firms are increasingly forming collaborative networks to develop the necessary capabilities for digital servitization. However, this process demands organizational changes related to environmental, technical, and relational conditions. This thesis aims to understand these conditions, analyzing inter-firm collaboration and data integration of networks in Smart Product-Service Systems (PSSs). We propose that environmental conditions, such as market and technology turbulence, affect the innovation performance in digital servitization, in which the inter-firm data integration in collaborative networks supports the process. These networks play an important role in delivering digital services in different servitized business models. We also propose that different configuration types of collaborative networks are possible for developing and delivering Smart PSS. To understand this phenomenon, first, we analyzed how inter-firm data integration moderates Smart PSSs in different environmental conditions and the development of different servitized business models based on service delivery through digital technologies. These hypotheses were tested based on collected data from the machine industry in Brazil, analyzed through ordinary least square regression with moderation. Then, we employed a multiple-case study approach to analyze different configurations of collaborative networks in Smart PSSs. We used case studies of companies in France, Italy, and Brazil. As a result, from the quantitative analysis, we found technological turbulence affecting the innovation performance of Smart PSSs, in which customer data integration supports more innovative outcomes to a certain degree. In addition, we found different combinations of service provision through digital technologies to develop different servitized business models, supported by the integration with different actors. From the qualitative analysis, we found that collaboration is related to the degree of innovation of the offering and showed how different types of collaboration result in different relational implications. This thesis demonstrates how product firms can collaborate with external actors to develop Smart PSSs, and what they require in terms of digital resources and relational assets, considering their strategic objectives under environmental conditions. The findings are summarized in a proposed model, which addresses research gaps in digital servitization literature and supports practitioners' guidance in this process.

Keywords: collaboration; integration; networks; digital technologies; digital servitization

RESUMO

Os fabricantes estão formando cada vez mais redes de colaboração para desenvolver as capacidades necessárias para a servitização digital. Entretanto, este processo exige mudanças organizacionais relacionadas às condições ambientais, técnicas e relacionais. Esta tese visa compreender estas condições, analisando a colaboração entre empresas e a integração de dados de redes em Sistemas Inteligentes de Produtos-Serviços (Smart PSSs). Propomos que as condições ambientais, tais como turbulências de mercado e tecnológicas, afetam o desempenho da inovação em serviços digitais, nos quais a integração de dados entre as empresas em redes colaborativas apóia o processo. Estas redes desempenham um papel importante na prestação de serviços digitais em diferentes modelos de negócios de serviços. Também propomos que diferentes tipos de configuração de redes colaborativas sejam possíveis para o desenvolvimento e fornecimento de Smart PSS. Para entender este fenômeno, primeiro analisamos como a integração de dados entre empresas modera os Smart PSSs em diferentes condições ambientais e o desenvolvimento de diferentes modelos de negócios servitizados com base na prestação de serviços através de tecnologias digitais. Estas hipóteses foram testadas com base em dados coletados da indústria de máquinas no Brasil, analisados através da regressão ordinária de mínimos quadrados com moderação. Em seguida, empregamos uma abordagem de estudo de múltiplos casos para analisar diferentes configurações de redes colaborativas em Smart PSSs. Utilizamos estudos de caso de empresas na França, Itália e Brasil. Como resultado, a partir da análise quantitativa, encontramos turbulência tecnológica afetando o desempenho de inovação dos Smart PSSs, nos quais a integração de dados de clientes suporta resultados mais inovadores até certo ponto. Além disso, encontramos diferentes combinações de prestação de serviços através de tecnologias digitais para desenvolver diferentes modelos de negócios na servitização digital, apoiados pela integração com diferentes atores. A partir da análise qualitativa, descobrimos que a colaboração está relacionada ao grau de inovação da oferta e mostramos como diferentes tipos de colaboração resultam em diferentes implicações relacionais. Esta tese demonstra como as empresas de produtos podem colaborar com atores externos para desenvolver Smart PSSs, e o que eles requerem em termos de recursos digitais e ativos relacionais, considerando seus objetivos estratégicos sob condições ambientais. As conclusões são resumidas em um modelo proposto, que aborda as lacunas de pesquisa na literatura sobre servitização digital e apóia a orientação dos profissionais neste processo.

Palavras-chave: colaboração; integração; redes; tecnologias digitais; servitização digital

RESUME

Les entreprises manufacturières forment de plus en plus de réseaux de collaboration afin de développer les capacités nécessaires à la servicisation digitale. Cependant, ce processus exige des changements organisationnels liés aux conditions environnementales, techniques et relationnelles. Cette thèse vise à comprendre ces conditions, en analysant la collaboration inter-firmes et l'intégration des données des réseaux dans les systèmes de produits et services intelligents (SPS). Nous proposons que les conditions environnementales affectent la performance de l'innovation dans la servicisation digitale, dans laquelle l'intégration des données inter-firmes dans les réseaux de collaboration soutient le processus. Ces réseaux sont importants pour la fourniture de services digitales dans différents modèles d'entreprise en servicisation. Nous proposons également que différents types de configuration de réseaux de collaboration soient possibles pour développer et fournir des PSS intelligents. Pour comprendre ce phénomène, nous avons analysé comment l'intégration des données inter-firmes modère les SPS intelligents dans différentes conditions environnementales et le développement de différents business modèles basés sur la fourniture de services par les technologies digitales. Ces hypothèses ont été testées sur la base de données collectées dans l'industrie des machines au Brésil, analysées par régression avec modération. Ensuite, nous avons utilisé une approche d'étude de cas multiples pour analyser différentes configurations de réseaux de collaboration dans les SPS intelligents. Nous avons utilisé des études de cas d'entreprises en France, en Italie et au Brésil. L'analyse quantitative a révélé que les turbulences technologiques affectent la performance d'innovation des SPS intelligents, dans lesquels l'intégration des données des clients soutient des résultats plus innovants dans une certaine mesure. En outre, nous avons trouvé différentes combinaisons de fourniture de services par des technologies digitales pour développer différents business modèles de la servicisation, soutenus par l'intégration avec différents acteurs. L'analyse qualitative nous a permis de comprendre le lien entre la collaboration et le degré d'innovation de l'offre, et ses implications relationnelles. Cette thèse démontre comment les entreprises manufacturières peuvent collaborer avec des acteurs externes pour développer des SPS intelligents, et ce dont elles ont besoin en termes de ressources numériques et d'actifs relationnels, compte tenu de leurs objectifs stratégiques dans des conditions environnementales. Les résultats sont résumés dans un modèle proposé, avec des contributions théoriques et pratiques.

Mot clés : collaboration ; intégration ; réseaux ; technologies digitales ; servicisation digitale

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1 INTRODUCTION

The ever-growing competition in product businesses led product firms to seek innovation in product and process dimensions, and their business models (ZOTT; AMIT, 2008). The product firms started to integrate services into their product offerings in the so-called product-service systems (PSSs) to address customer needs and improve their business, obtaining more competitive advantage (BAINES *et al.*, 2007). The process of integrating services to products was coined servitization in 1988 by Vandermerwe and Rada (1988). Since then, servitization has become a consolidated research theme due to its potential to create new revenue streams, better address customer needs, innovate offerings and increase customer loyalty (BAINES *et al.*, 2017; EGGERT; THIESBRUMMEL; DEUTSCHER, 2015; SACCANI; VISINTIN; RAPACCINI, 2014). The obtained benefits will depend on the type of services the companies will provide to their customers. More advanced services bring more opportunities for improved innovation performance and business growth (BAINES *et al.*, 2020; CHEN *et al.*, 2021). Scholars in the servitization field have extensively researched the potential to bring more competitive advantage through innovative solutions, also accessing new markets (MARTINEZ *et al.*, 2017). However, the main research gap remains in how product firms can efficiently and effectively exploit this process (BAINES *et al.*, 2017). Servitization implies developing new capabilities that exceed the product firms' expertise, usually demanding high investments that do not necessarily bring the expected correspondingly higher returns (GEBAUER; FLEISCH; FRIEDLI, 2005). This issue relates to the contingency of servitization on environmental factors, such as technology and market turbulence (CHEN, K. H. *et al.*, 2016; CUSUMANO; KAHL; SUAREZ, 2015). To overcome this problem, two inter-linked strategies have been alternatives pursued by product firms: the implementation of digital technologies and the development of capabilities through inter-firm collaboration (GAIARDELLI *et al.*, 2021; KOHTAMÄKI *et al.*, 2019; SHAH *et al.*, 2020).

The potential of digital technologies to automatize and improve operations resulted in the digitalization phenomena, revolutionizing industries and service businesses (GOBBLE, 2018). In the convergence of digitalization and servitization, product firms could successfully integrate digital services with products and deliver services with better cost-

efficiency thanks to the scalability provided by these technologies (CHEN *et al.*, 2021; FRANK *et al.*, 2019). This convergence has become a growing sub-research field of servitization called digital servitization (PIROLA *et al.*, 2020). In this context, digital technologies enable new ways of value creation and capture in Smart PSSs (KOHTAMÄKI *et al.*, 2019), meeting individual customer needs with more sustainability through intelligent systems (PIROLA *et al.*, 2020). Digital technologies can improve both the back- and front-end offices' efficiency and the connection between them (FRANK; DALENOGARE; AYALA, 2019; MEINDL *et al.*, 2021). Through digital technologies, product firms can create different digital channels to deliver services to the customers on a multichannel system, increasing the flexibility in the value provision (SOUSA; AMORIM, 2018). In this context, data generation, collection, and analysis are core activities of Smart PSSs (OPRESNIK; TAISCH, 2015; PICCOLI; PIGNI, 2013), which allow capabilities such as the remote monitoring, optimization, and autonomy, enabling more efficient advanced services to the customers (GRUBIC; JENNIONS, 2018; KOHTAMÄKI *et al.*, 2019; MARCON *et al.*, 2022). Thus, data-processing activities are a major concern for product firms in Smart PSSs, in which data is streamed from different sources, such as the customers, suppliers, and service providers within connected networks (OPRESNIK; TAISCH, 2015).

The second strategy pursued by product firms to support the servitization process is inter-firm collaboration. Collaboration among actors has been considered an important strategy to operationalize the transformational process of servitization (KAHLE *et al.*, 2020; PAIOLA *et al.*, 2013). The service-related capabilities and its deployment with products require a costly structure (MARCON *et al.*, 2022). In order to reach the customers and respond to their needs, the whole supply chain must be more integrated to execute and assess the services (DAIN; PACHÉ; CALVI, 2019; SHAH *et al.*, 2020). Thus, in a servitized context, the manufacturer is more likely to collaborate with other actors, such as suppliers and service providers, forming different collaborative configurations of networks to develop and deliver Smart PSSs. (AYALA *et al.*, 2017; PAWAR; BELTAGUI; RIEDEL, 2009). Inter-firm collaboration and network integration are key sources of innovation, improving the value creation and generating opportunities for all engaged actors to capture more value with the solutions (BELLAMY; GHOSH; HORA, 2014; FINNE; HOLMSTRÖM, 2013). This context leads to strengthening the operational linkages of the product firm's network and alters the structural arrangements of

relationships (BASTL *et al.*, 2012; GEBAUER; PAIOLA; SACCANI, 2013), in which relational norms complement legal contracts through informal mechanisms of governance (BASTL *et al.*, 2012), such as trust (LUSCH; VARGO; TANNIRU, 2010). These mechanisms are necessary to incentivize the required open exchange of information among the actors and to incentivize their participation in the network (VARGO; LUSCH, 2011). Thus, inter-firm collaboration can create superior knowledge-based resources and capabilities related to the service provision, improving product firms' business and innovation performance in the servitization process (BUSTINZA *et al.*, 2019).

In digital servitization, collaboration is two-fold. On the one hand, product firms continue in joint activities to develop more advanced solutions, as in the case of Kone, which developed smart elevators with the intelligent systems provided by IBM (ARDOLINO *et al.*, 2017). On the other hand, the collaboration also approaches data integration with external actors to create a more responsive supply chain, able to address customers' needs in real-time (JOHNSON; MENA, 2008; SHAH *et al.*, 2020). The data integration allows new ways to include external actors to develop and deliver Smart PSSs, as in the case of Canon, which provides pay-per-print solutions to their customers with a real-time connection through cloud systems. Outsourced dealers are connected to these systems, obtaining real-time information on machine status and providing more responsive maintenance services (ARDOLINO *et al.*, 2017). In addition, the data integration generates more rich contextual data for the service provision, which is necessary to understand the business environment and leverage the information generated by the solutions (CENAMOR; RÖNNBERG SJÖDIN; PARIDA, 2017), improving the servitized business model (GRUBIC; JENNIONS, 2018). For example, John Deere collects data on crop yields through their farming equipment and then sells it to DuPont, who sells seeds and agricultural consulting for the same customer. The data provision improves the value proposition of both companies as the customer obtains more information about its business performance (DELOITTE, 2014). However, because of the required integration of systems and interoperability issues for data integration, Smart PSSs have become more complex. Product firms must overcome digitalization barriers to create a reliable infrastructure for data exchange, requiring even more collaborative efforts among the parties and the inclusion of new actors in the network on a service ecosystem level (BREIDBACH *et al.*, 2018; MARCON *et al.*, 2022).

Research related to digital servitization has been growing significantly in the last years (PIROLA et al., 2020). Sklyar *et al.* (2019) evidenced that the digital process requires a stronger integration of the whole organization. Shah *et al.* (2020) found that providing basic services demands stronger integration with the suppliers while providing advanced services demands stronger integration with the customer. Tronvoll *et al.* (2020) establish data management and collaboration as key roles for the transformation process of digital servitization to maintain competitiveness through efficiency improvement and align the value proposition to the customers' needs through closer interactions. Despite advancements in these topics, many research gaps remain, preventing a full comprehension of the transformational process of digital servitization. In a systematic literature review on digital servitization, Raddats *et al.* (2019) highlight research gaps on the collective development of capabilities and shared risks of product firms and their supporting network. In addition, the authors conclude a lack of research concerning trade-offs of service and product innovation, and the role of digital technologies, especially in developing service delivery processes. Paschou *et al.* (2020) corroborate this research gap, concluding that most studies consider the role of only a few digital technologies, usually IoT. The authors also identify most studies in developed countries and considering a fragmented view on digital servitization-related themes, such as new business models, value co-creation, and performance improvement. Overall, the existing literature suggests studies contemplating multiple actors within networks and analyzing their interactions for the development and delivery of Smart PSSs (SKLYAR *et al.*, 2019b; TRONVOLL *et al.*, 2020); highlighting the need to identify the role of digital technologies (ARDOLINO *et al.*, 2017; KOHTAMÄKI *et al.*, 2019); and to analyze with a holistic approach considering environmental factors that influence the innovation performance in digital servitization (FRANK *et al.*, 2022; PIROLA et al., 2020; VISNJIC; RINGOV; ARTS, 2019).

Considering the major roles of collaboration in networks, data integration, and the environmental factors in digital servitization, the present thesis addresses the following research questions: (i) *How inter-firm collaboration and data integration in networks support product firms to obtain improved innovation performance in digital servitization?* (ii) *Which conditions, requirements, and barriers affect inter-firm collaboration and data integration in this context?*

1.1 RESEARCH THEME AND OBJECTIVES

This thesis lies at the intersection of inter-firm management, technology management, and strategic management research fields. The theme of this research concerns inter-firm collaboration and data integration in the digital servitization process.

The general objective of this thesis is *to develop a model that explains the role of collaboration with the main actors of service ecosystems (other business units of the same organization, suppliers, and customers) in a digital servitization context*. This model aims to clarify the environmental factors, technological requirements, and relational implications of collaborating with external actors through digital technologies in digital servitization. The aim is to explore the two coins of collaboration in digital environments. First, the collaboration related to data integration with external actors is required to create an efficient information exchange system and respond to market needs (CHEN *et al.*, 2021; OPRESNIK; TAISCH, 2015). This perspective considers the role of digital technologies and network integration to support their implementation in Smart PSSs. Second, the collaboration is represented by joint activities with resource sharing, capabilities exchange, and the development of relational assets (DYER; SINGH; HESTERLY, 2018). This perspective is based on social elements, i.e., trust, commitment, reciprocity, and power, identified by the supply chain management literature as determinants for the relationship among the actors (CROPANZANO; MITCHELL, 2005; WU *et al.*, 2004). In addition, this model considers the main driver of the digital servitization process, the increased innovation performance of product firms for a more competitive advantage in their markets (COREYNEN *et al.*, 2020).

In this context, to understand how product firms are collaborating with other companies in digital servitization, this thesis has the following specific objectives:

- a) To identify the role of data integration with external actors through Smart PSSs in environmental turbulence for increased innovation performance in digital servitization.
- b) To identify the role of integration with external actors through Smart PSSs for the service provision in different servitized business models.

- c) To identify the different configurations of inter-firm collaboration in Smart PSSs and the relational implications for each configuration.

1.2 MOTIVATION

The research theme takes place in two main environments: (i) inter-firm collaboration, (ii) network data integration; and consider four main research areas (i) Digital servitization, (ii) Business Environment conditions, (iii) Organization information processing, and (iv) Relational view and Social Exchange Theory. Digital servitization is a growing research field. In the literature review of Pirola *et al.* (2020), they found that research related to digital servitization has grown on average 30% each year in the last six years, as shown in Figure 1.1. Servitization is a strong global trend in manufacturing, leading companies to adapt their business models to understand and respond to customer needs. The trend is reinforced when combined with digitalization, which brings many opportunities for business growth, altering the industry competition. Thus, digital servitization is a trending theme for calls for papers in important journals of different areas, such as operations management (International Journal of Operations Management – IJOPM), marketing (Industrial Marketing Management), and information systems (Computers in Industry), and others.

As stated by Baines *et al.* (2017), the most important gap in digital servitization literature is understanding the process and its organizational transformation of product firms. The development of services can become too costly for these firms, in which some companies file for bankruptcy (BENEDETTINI; SWINK; NEELY, 2016). Visnjic, Ringov, and Arts (2019) suggest this may occur due to a mismatch between the types of services offered by these firms and their industry conditions. Digital servitization is contingent on environmental conditions, such as market and technological turbulence, the change in customer preferences, and product technology (FRANK *et al.*, 2022). Although studies indicate that firms within market and technological turbulence contexts are more prone to adopt a digital servitization strategy, it is unclear how these conditions affect the process (CUSUMANO; KAHL; SUAREZ, 2015; VISNJIC; RINGOV; ARTS, 2019). Moreover, the existent research implies the environment as one of the determinants for innovation performance of product firms, the main driver of digital servitization

(COREYNEN *et al.*, 2020). However, there are no studies about the support of external actors to address environmental changes in this context (FRANK *et al.*, 2022).

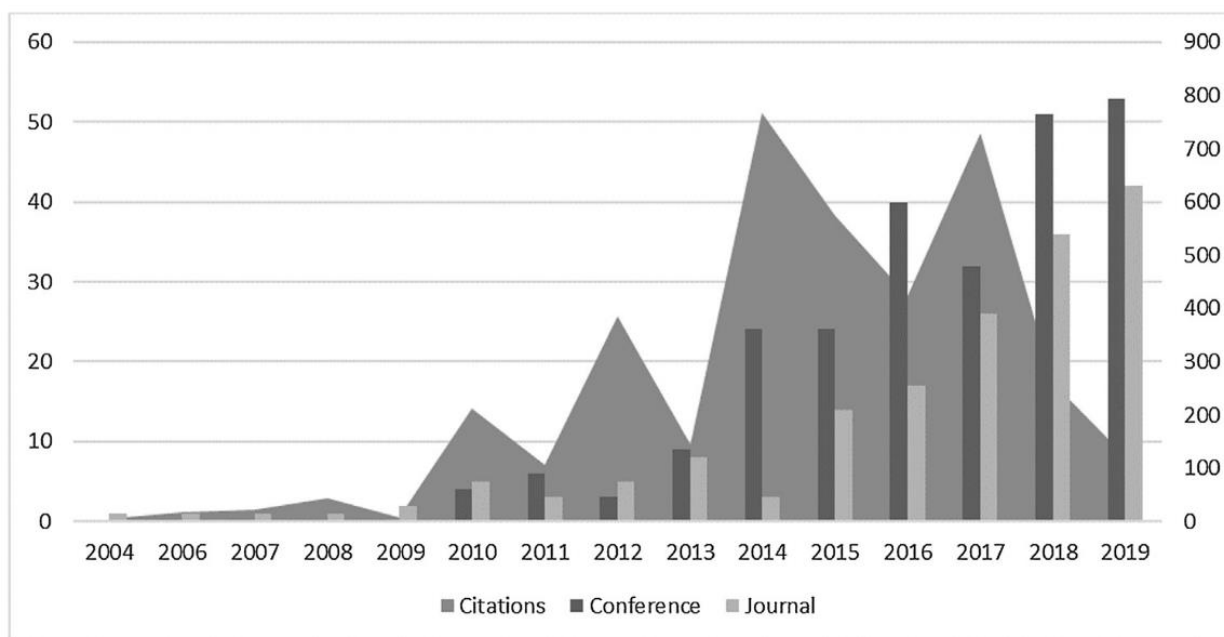


Figure 1.1 Number of papers related to digital servitization research published per year (PIROLA *et al.*, 2020)

Inter-firm collaboration is a broad and important research topic within the supply chain management field (ATEŞ; VAN DEN ENDE; IANNIELLO, 2015). The increased competition faced by product firms leads to significant transformations of their operations, in which a network level of analysis must be considered to explain and enable superior individual firm performance, as stated by the relational view theory (DYER; SINGH; HESTERLY, 2018). Product firms must be open to exchange with different companies, such as product component suppliers, digital technology suppliers, service providers, and customers, to access different sources of innovation (CHESBROUGH, Henry; LETTL; RITTER, 2018). At the same time, creating relational assets demands significant investments by the companies (CANNON; PERREAULT, 1999). Thus, according to the Social Exchange Theory (SET), understanding relational implications aiming to increase innovation is fundamental for the competitiveness of companies. Although inter-firm collaboration is a mature research field in supply chain management, it is under-explored in digital servitization, in which collaboration is a key strategy for the success of the process (CHEN *et al.*, 2021; KOHTAMÄKI *et al.*, 2019). Several studies indicate significant changes in the supply chain in digital servitization, in which the developed solutions, the Smart PSSs, require an integrated network for its functioning

and delivery (BAINES *et al.*, 2017; FINNE; TURUNEN; ELORANTA, 2015; KOHTAMÄKI *et al.*, 2019; SKLYAR *et al.*, 2019b). Thus, the literature acknowledges the need for external support from inter-firm collaboration. Baines *et al.* (2017) indicate that research on network structures and configurations, capabilities, relationships for service support, degrees of collaboration, and power dynamics within inter-organizational networks are emerging topics in servitization. This is corroborated by other studies focused on digital servitization (KOHTAMÄKI *et al.*, 2019; SKLYAR *et al.*, 2019).

In digital environments, the collaboration with external actors benefits from digital technologies and data exchange. Cui *et al.* (2022) found that information transparency, integration of the management information system, and improving large data processing ability are the most important factors influencing the success of supply chain collaboration. In digital servitization, the transfer, collection, and analysis of data are key activities for the future of the competitive advantage of product firms (OPRESNIK; TAISCH, 2015; TRONVOLL *et al.*, 2020). Opresnik and Taisch (2015) consider digital servitization within a service ecosystem, in which the data exchange enables further inter-firm collaboration and more advanced services based on digital technologies, a growing trend to develop smarter capabilities related to operations and management (PIROLA *et al.*, 2020). In this context, the collaborative networks forming service ecosystems provide a valuable pool of resources that support the development and delivery of Smart PSSs (PASCHOU *et al.*, 2020; STRUYF *et al.*, 2021). These networks are integrated through data exchange in shared information systems, which allows the applications of intelligent systems while combining resources and capabilities with other actors (OPRESNIK; TAISCH, 2015). This arrangement support product firms in the organizational fit between information-processing needs and information process capability according to the Organizational Information-Processing (OIP) theory. By matching the information-processing needs and capabilities, product firms can understand their business environment, reduce uncertainties, and support more efficient inter-organizational activities (PREMKUMAR; RAMAMURTHY; SAUNDERS, 2005).

The most recent literature reviews on digital servitization corroborate the need for further studies on these related themes of digital servitization. Raddats *et al.* (2019) highlight the need for future studies to expand the product firm-focused perspective into a multi-actor perspective. The authors propose 11 research priorities in digital servitization. Five

research priorities are related to the synergy with customers, suppliers, or a network of actors, aiming to address research gaps on the collective development of capabilities and shared risks. Two research priorities on the service delivery processes to address the lack of comprehension of the role of digital technologies. One research priority concerns trade-offs of service and product innovation. Kohtamäki *et al.* (2019) conclude that business models in digital servitization must adopt an ecosystem perspective. The authors propose ten research directions to clarify the process. Three research directions concerning the role of digital technologies in business model change and competitive advantage. Five research directions related to the role of ecosystems for digital servitization, including the need to study paradoxical tensions and social elements among partners, how digitalization changes collaboration, the co-creation and capture of value with ecosystem partners, and the platform orchestration of multi-actors business models. Pirola *et al.* (2020) corroborate these research directions by proposing future studies considering the interactions of Smart PSS providers with their ecosystem and addressing internal and external determinants of the innovation path of digital servitization. In parallel, Paschou *et al.* (2020) conclude that most studies consider only a few digital technologies in digital servitization. The authors call for further studies on digital technologies' combinatory effects and benefits, highlighting the need to carry out prescriptive and confirmatory research as most studies are solely based on one or a few case studies. In addition, the authors identify that most studies take place in developed countries and consider a fragmented view on digital servitization-related themes, such as new business models, value co-creation, and performance improvement. They suggest studies in emerging countries and adopting a holistic approach. Lastly, Marcon *et al.* (2022) suggest theoretical advancements in the role of external actors to maximize revenues and reduce costs in digital servitization.

1.3 RESEARCH DESIGN

Considering the definition of this research theme, objectives, and motivation, this section describes the design of the research. Firstly, this section presents an overview of the methodology applied and, subsequently, the organization of the thesis.

1.3.1 RESEARCH METHODOLOGY

This research has a mixed approach using quantitative and qualitative methods in different research design steps (MARCONI; LAKATOS, 2010). The mixed approach is suitable to reach the objectives set and consider the richness of a phenomenon, offering a complete picture (VENKATESH; BROWN; BALA, 2013).

In the first part of the thesis, Article 1 and 2, the research is explanatory, once the aim is to confirm the proposed hypothesis on the studied phenomena. The second part of the thesis, Article 3, consists of exploratory research, aiming to understand the mechanisms and determinants of inter-firm collaboration. In addition, the research also has used a triangulated approach once the thesis combines different sources and methods of data collection. Regarding the methods applied, the research is classified as a survey in the explanatory part, once quantitative data of characteristics and opinions of practitioners was collected (FOWLER, 2013). The collected data was analyzed through regression analyses, a widely adopted method in operations management research (PENG; LAI, 2012). In the exploratory part, the research is classified as a case study, as specific case studies are investigated to comprehend better the phenomena (KETOKIVI; CHOI, 2014; YIN, 2014). Overall, the research has a conceptual theory method, extending the comprehension of identified research gaps and using existing concepts in the literature.

1.3.2 METHOD OF WORK

In order to address each of the specific objectives, the development of the research is divided into three steps, represented by articles. By combining the three articles, the main research objective is reached. The thesis structure by articles is presented in Table 1.1 with a subsequent description of the articles regarding their objectives and methods. The Figure 1.2 shows the relationship among the articles to include the research areas of the thesis.

Table 1.1 Structure of the research development

	Research question	Research objectives	Theoretical lens and environments	Method
1st article	Do Smart PSSs support product firms to improve innovation performance in environmental turbulence? What is the role of inter-firm data integration and digitalization barriers in digital servitization?	Identification of the environmental factors and the role of inter-firm data integration for digital servitization	Environmental conditions Network data integration	Quantitative Survey OLS with mediation and moderation
2nd article	To what extent do different service ecosystem actors contribute through data integration with servitized companies to support the multi-channel digital service delivery in Smart PSS business models?	Identification of the role of digital technologies and inter-firm data integration for servitized business models	OIP Network data integration	Quantitative Survey OLS with moderation
3rd article	How can inter-firm collaborations be configured for the offering of Smart Product-Service Systems	Definition of the inter-firm collaboration typology in Smart PSSs	SET Inter-firm collaboration	Qualitative Multiple case study

Article 1 – “*Innovation performance of digital servitization in environmental turbulence: the role of inter-firm data integration and digitalization barriers*”. The article aims to understand the role of environmental turbulence (technological and market turbulence), inter-firm data integration, and digitalization barriers in the innovation performance of digital servitization. We confirm hypotheses from the literature by using regression analyses with mediation effects (Smart PSSs) and moderations (environmental turbulence, inter-firm data integration, and digitalization barriers) on a sample of 102 equipment manufacturers in Brazil. The results show a positive effect of technological turbulence in innovation performance through Smart PSSs, in which the customer data integration supports its development. However, the results indicate such positive association is limited, in which beyond a certain degree of integration, the product firms decreases innovation performance. The supplier data integration positively moderates Smart PSS development in market turbulence, but no significant results on innovation performance were found in this context. The paper shows the implications of network

data integration to understand environmental factors and improve innovation performance in digital servitization.

Article 2 – “*Multichannel digital service delivery and service ecosystems: the role of data integration within Smart Product-Service Systems*”. This article considers the provision of services in Smart Product-Service Systems (PSS) based on digital technologies, which require external data from collaborative networks. This article aims to understand how service provision through digital channels (Smart Products, Cloud Services, and Smart Work-Based Services) can be supported by the data integration from three actors in service ecosystems (other business units, suppliers, and customers) to provide different Smart PSS business models. The research is based on a survey with 92 manufacturers of a Brazilian association of equipment builders. The results provide three frameworks to describe how real-time data from the network and digital technologies are combined in each business model.

Article 3 – “*Inter-firm collaboration for Smart Product-Service Systems: a Social Exchange Theory perspective*”. Considering inter-firm collaboration as an important strategy for value creation and capture in digital servitization, this paper aims to define the main configurations of inter-firm collaboration for Smart Product-Service Systems (PSSs). Based on the literature review, it is proposed four configurations for collaboration. Subsequently, a multiple-case study is applied, conducting one case study for each type of collaboration. These cases were analyzed according to elements of the Social Exchange Theory (SET): trust, commitment, reciprocity, and power. The findings show that the configuration type for collaboration varies according to the level of innovation sought in the Smart PSS offer. For each type of collaboration, different arrangements of the SET elements can be found. The study provides an in-depth analysis of inter-firm collaboration for Smart PSS.

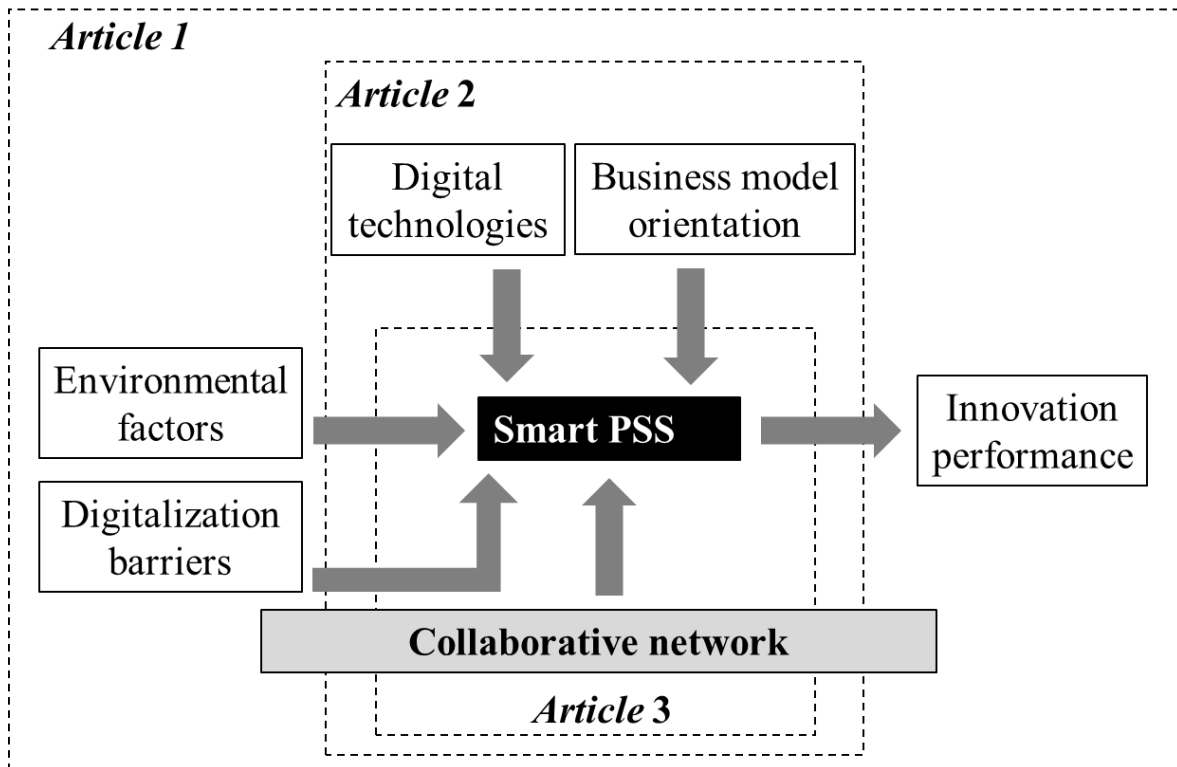


Figure 1.2 Relationship among the three articles of the thesis

1.4 RESEARCH SCOPE AND LIMITATIONS

The research development has a predefined scope, as follows. The research aims to understand collaboration in digital servitization, considering both relational and technical implications. The research is limited to the boundary mechanisms of the collaboration of product firms in their networks. Even though internal elements of the firms are considered, this research does not consider an in-depth study of internal drivers and determinants for inter-firm collaboration.

The explanatory part of the thesis only considered a Brazilian association of the machine industry. This industry was chosen once the machine and equipment sector has a high potential to adopt a servitization strategy and develop digital services, following other studies in servitization contexts (GEBAUER; FLEISCH; FRIEDLI, 2005; KAHLE et al., 2020). In addition, the association was chosen due to its engagement in promoting digitalization and innovation initiatives to support the competitive advantage of the associated companies. However, this limits the findings, preventing generalization for other industries. In the exploratory part, the collaboration is analyzed in established networks of developed Smart PSSs. Thus, the transition and transformation phases of the

collaborative networks are not considered, nor applied longitudinal methods that explain the trajectory of inter-firm collaboration, as the objective is to understand its relational and power-dependency implications in digital servitization. However, important antecedent elements for collaboration are considered in the explanatory part.

This thesis focuses on collaboration considering data integration with external actors in networks. The data integration perspective refers to information sharing through integrated inter-organizational systems, connecting cross-boundary actors. It is important to highlight the focus in the research area of Supply Chain Collaboration, more specifically the inter-firm collaboration, and not Supply Chain Integration. Although some studies use both terms almost synonymously due to their interrelation, the literature distinguishes collaboration and integration in some characteristics (CAO; ZHANG, 2011). Collaboration means the joint of two or more independent companies to plan and execute supply chain operations (SIMATUPANG; SRIDHARAN, 2002). Integration is the degree a product firm strategically collaborates with partners in the supply chain, efficiently managing flows of resources and information in cross-boundary processes to provide increased value to the customer (FLYNN; HUO; ZHAO, 2010). Both concepts consider inter-organizational process integration and collaborative activities, but the former focus on relational communication and value co-creation, while the latter concerns the central control of inter-related processes by contract means (CAO; ZHANG, 2011). In this sense, even though data integration greatly supports supply chain integration, it is not fully representative of this construct.

Lastly, most of the existent research on digital servitization considers an ecosystem level of analysis, as digital-based service operations require inter-firm support within ecosystems (BREIDBACH *et al.*, 2018; CHEN *et al.*, 2021; KOHTAMÄKI *et al.*, 2019). An ecosystem perspective is important considering the multiple actors engaged in the digital servitization of a product firm. However, an ecosystem approach is indifferent to how the exchanges among the integrated actors are coordinated and which mechanisms determine these exchanges (KOHTAMÄKI *et al.*, 2019). Considering that digital servitization likely results in closely integrated operations with external actors, inter-firm collaboration and networks are suitable to complement the ecosystem approach and understand the inter-organizational changes required for the transformation process.

1.5 THESIS STRUCTURE

This thesis proposal is structured into six main chapters. This first chapter presented the research context, explaining the objectives and justification for research and the methods applied. The following chapters 2, 3, and 4 consists of the developed articles for the research. The fifth chapter presents the general results of the thesis, integrating the results of the previous three chapters. Lastly, the final chapter brings the conclusions of the thesis, with theoretical and practical contributions.

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2 ARTICLE 1 - DIGITAL SERVITIZATION IN TURBULENT ENVIRONMENTS: WHEN INTER-FIRM DATA INTEGRATION AND DIGITALIZATION BARRIERS ARE KEY FACTORS FOR INNOVATION PERFORMANCE

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Abstract

The main objective of digital servitization is to achieve increased innovation performance. However, the process can be affected by environmental factors, such as market and technological turbulence, and digitalization barriers. In such a context, inter-firm data integration with the servitization ecosystem can support the process. In this context, we aim to understand how Smart Product-Service Systems (PSSs) enable more innovative outcomes, considering contextual factors and the role of supplier and customer data integration. We consider the mediation effect of Smart PSS for increased innovation performance in environmental turbulence, with moderation effects of inter-firm data integration and digitalization barriers (internet infrastructure issues and cybersecurity threats). Our analysis is based on a survey of 102 product firms. Our regression results show that Smart PSSs mediate increased innovation performance in contexts with high technological turbulence. Although supplier data integration supports the development of Smart PSSs in market turbulence contexts, we found that only customer data integration supports increased innovation performance. However, the results show the existence of an optimal level of customer data integration, in which more integration can decrease innovation performance. We also found digitalization barriers negatively moderating the development of Smart PSS in both market and technological turbulence contexts. Our study provides a broad perspective of digital servitization by integrating technological, environmental and organizational factors into the Smart PSS offering.

Keywords: digital servitization; Smart PSSs; environmental turbulence; inter-firm data integration

2.1 INTRODUCTION

To achieve competitive advantage in complex markets, many product firms are integrating services with product offerings in the so-called Smart Product-Service Systems (Smart PSSs) as part of the digital servitization strategy (KOHTAMÄKI *et al.*, 2019; MARCON *et al.*, 2022). Digital servitization focuses on improving the innovation performance of product firms for increased competitive advantage (FREIJE; DE LA CALLE; UGARTE, 2021; MARTÍN-PEÑA; SÁNCHEZ-LÓPEZ; DÍAZ-GARRIDO, 2019). The search for improved innovation outcomes in new solutions development and new markets entry are the main drivers for product firms to adopt this strategy (COREYNEN *et al.*, 2020). To achieve better outcomes in digital servitization, product firms need to address both internal and external issues, as the process is influenced by environmental factors. Prior studies have shown that market and technological turbulence create more pressure for product firms to adopt digital servitization as a response strategy (FRANK *et al.*, 2022). By providing services with products, product firms can better understand customer needs and reduce some technology adoption risks (CUSUMANO *et al.*, 2015; VISNJIC *et al.*, 2019; SHAH *et al.*, 2020).

Digitalization allowed more integration of product firms with important external actors to create value (SHAH *et al.*, 2020; SKLYAR *et al.*, 2019). In digital environments, these actors can exchange data in real-time improving different activities throughout the supply chain. The data integration with suppliers allow more synchronous production operations, fastening customization services (BOEHMER *et al.*, 2018; FRANK *et al.*, 2022). Customer data integration supports product firms to understand customer demands and how customers use the solutions provided, a useful information to improve existing solutions and to create new ones (FREIJE; DE LA CALLE; UGARTE, 2021; RYMASZEWSKA; HELO; GUNASEKARAN, 2017). However, to take advantage of the digitalization benefits, product firms also need to overcome barriers related to internet-based solutions (LIU *et al.*, 2019; MARCON *et al.*, 2019; KAHLE *et al.*, 2020). The most advanced features of Smart PSSs demand data-processing capabilities enabled by technologies like Internet of Things (IoT), cloud computing and data analytics (ASGHARI; RAHMANI; JAVADI, 2019; OPRESNIK; TAISCH, 2015). Thus, issues for internet connectivity can hamper the use of Smart PSSs for more innovative outcomes.

The digital servitization literature has been addressing the before mentioned issues. Cusumano et al. (2015) and Visnjic et al. (2019) proposed that different types of services in PSSs support product firms to better address technological turbulence throughout different product lifecycle stages. Frank et al. (2022) found evidence of market and technological turbulence as antecedents of the servitization process for some types of service offerings. Regarding inter-firm integration, Shah et al. (2020) confirm the requirement of more integrated supply chains according to the offered service types, in which basic services demand supplier integration, while advanced services call for customer integration. In the same vein, Marcon *et al.* (2022) showed the different levels of digital service offering in servitized solution require the integration of external actors to increase digital capabilities, many of them supported by means of data integration. However, despite the advancements in the literature, the existing studies have analyzed all these related topics separately. Thus, there is a need for an investigation of digital servitization considering an integrative perspective of environmental, organizational, and technological factors to understand how product firms can obtain improved innovation performance in the process (FREIJE; DE LA CALLE; UGARTE, 2021). As stated by Paschou et al. (2018) and Pirola et al. (2020), such integration is important for a full comprehension of the digital servitization process, enabling conceptual models to guide product firms on this journey and to develop a theory for digital servitization. Thus, this article aims to answer: *Does Smart PSSs support product firms to improve innovation performance in environmental turbulence? What is the role of inter-firm data integration and digitalization barriers in digital servitization?*

This article is designed to analyze how Smart PSSs mediate market and technological turbulence, allowing product firms to obtain increased innovation performance, and how the inter-firm data integration moderates the development of Smart PSSs in this context. Additionally, we also explore the effect of digitalization barriers regarding technology adoption for digital servitization, due to the growing importance of digital technologies (PASCHOU *et al.*, 2020). We performed regression analyses with mediation and moderation effects on a sample of 102 product firms in Brazil's machine and equipment industry, confirming existent propositions in digital servitization literature.

Our findings show that in contexts with high technological turbulence, product firms are more prone to implement digital servitization and to obtain increased innovation

performance with Smart PSSs. The findings suggest the importance to be integrated with customers through data exchange, but such integration have an optimal level. Beyond this level, more integration is not followed by more innovation performance. In parallel, supplier data integration was found positively associated with Smart PSSs development in market turbulence, which suggests suppliers support product firms to respond to market fluctuations, but not necessarily for improved innovation outcomes. Lastly, we confirmed that digitalization barriers related to internet connectivity can hamper the functioning of Smart PSSs, a call for attention for product firms in digital servitization when facing business environment challenges..

2.2 THEORETICAL BACKGROUND AND HYPOTHESES

2.2.1 DIGITAL SERVITIZATION IN ENVIRONMENTAL TURBULENCE

Digital servitization is a process that allows product firms to offer digital services combined with products in Smart Product-Service Systems (Smart PSSs). In Smart PSSs, the service component considers the integration of services with the product – embedded in smart products and provided through remote systems, e.g. cloud systems (GRUBIC, 2018; PORTER; HEPPELMANN, 2014) – and the value change of product business models. According to Cusumano, Kahl, and Suarez (2015), in PSS business models with product orientation, services can complement a product’s functions or substitute its sale. The complementary services can be *Smoothing* services, basic services that only “smooth” the product sale or usage without changing its value, such as maintenance and technical support. In more advanced complementary services, the manufacturing company will change, expand or adapt the product’s functionalities, changing its value to the customer. These so-called *Adapting* services consist of major customizations, consulting for new product applications, and product adaptation for integration with other solutions. In *Substituting* services, the manufacturing company sells the product as a service, changing its ownership through leasing functionalities.

These three types of PSS business models show how services change the value proposition of product firms by transforming different business dimensions. These dimensions are affected by external factors of the product firms (FRANK et al., 2022; TRONVOLL et al., 2020), as the process is influenced by environmental aspects of the industry structure. From the different potential influencing factors, the literature

acknowledges especially the environmental turbulence as a key aspect of the decision to servitize (FRANK *et al.*, 2022; VISNJIC; RINGOV; ARTS, 2019). According to Hanvanich *et al.* (2006), environmental turbulence is the magnitude of changes and unpredictability of environmental variables, represented by market and technological turbulence.

Market turbulence is defined by the unmatched product needs between new and existing customers or by the constant change of product preferences of existing customer. By integrating services in product offerings, product firms can better respond to market turbulence (FRANK *et al.*, 2022). As services demand more customer interaction, product firms can anticipate customer needs and perform the required adaptations for the market changes. Meanwhile, customers can receive better outcomes with the received solutions, such as increased product performance, process improvement, and more (FRANK *et al.*, 2019; VISNJIC; RINGOV; ARTS, 2019). In addition, firms can provide the customers lower risk offerings by keeping the ownership of the solution and being responsible for its functioning, making the customer feel safer in uncertain market scenarios. These benefits increase customer loyalty to the product firms, supporting them to retain and increasing market share (FRANK *et al.*, 2022).

Technological turbulence is defined as the change of technologies applied in product industries, which brings uncertainties for technology adoption by customers (WEISS; HEIDE, 1993; FRANK *et al.*, 2022). With lower risks solutions, the customer will feel safer investing in products with more innovative technology that might be outdated sooner than expected. Cusumano, Kahl and Suarez (2015) show how different servitized offerings can support product sales throughout different product lifecycle stages. In industries with new technology, product firms benefit from substitute and adapting services. The former exempts the customer from assuming the risks of the solution, while the latter allows modifications to adapt for specific customer needs through customization. In matured industries, the product firms can benefit from services that will complement the value of the product in order to differentiate it from competitors (VISNJIC; RINGOV; ARTS, 2019).

The servitization literature recognizes that product firms within industries of higher environmental turbulence, such as market and technological turbulence, are more prone

to adopt a servitization strategy. Chen et al. (2016) demonstrated that high market turbulence influences new product development performance, especially in situations with high levels of service innovation. Visnjic et al. (2019) found empirical evidence that technological uncertainty encourages product firms to offer product-oriented PSSs. In another study (VISNJIC; WIENGARTEN; NEELY, 2016), the authors also found evidence of PSS supporting product innovation performance in the long term. Frank et al. (2022) confirmed market and technological turbulence as antecedents of some service business dimensions of the servitization when the process is oriented to customization. Overall the existing literature presents partial empirical support for Smart PSSs improving the innovation performance of product firms within turbulent environments, especially considering higher innovation outcomes, such as the entry of new markets through service provision (CUSUMANO; KAHL; SUAREZ, 2015; FRANK *et al.*, 2022). By developing and delivering Smart PSSs, product firms can obtain knowledge about the customers, anticipate market changes, and properly address customer needs and uncertainties regarding technology adoption. As a result, product firms can innovate their offerings, reconfigure themselves to seize new opportunities, and access new markets in turbulent environments (COREYNEN *et al.*, 2020; VISNJIC; RINGOV; ARTS, 2019). Thus, considering the potential effect of turbulence on digital servitization and the potential of Smart PSSs to improve innovative outcomes of the product firms, we propose the following hypothesis:

***H1:** The development and delivery of Smart PSSs support product firms to improve innovation performance in contexts with high market turbulence (**H1a**) and technological turbulence (**H1b**).*

2.2.2 ENABLERS AND BARRIERS FOR DIGITAL SERVITIZATION IN TURBULENT ENVIRONMENTS

The implementation of a business model in digital servitization demands the development of dynamic and operational capabilities to provide Smart PSSs, in which digital technologies play a key role (COREYNEN *et al.*, 2020; TRONVOLL *et al.*, 2020). In general, services are provided through knowledge-intensive activities throughout the supply chain. Digital technologies facilitate knowledge transfer and enable more efficient and advanced service capabilities, especially considering their high scalability that lowers

the overall costs of service provision (BARRETT *et al.*, 2015). These so-called digital capabilities are enabled by the Internet of things, cloud computing, and data analytics, which benefit from analyzing data generated, collected, and combined from different sources, supporting increased value creation (ZAMBETTI *et al.*, 2021; MARCON *et al.*, 2022). For this purpose, exchanging data with external actors through inter-firm data integration facilitates product firms to enable more advanced features of Smart PSSs (STRUYF *et al.*, 2021).

The inter-firm data integration supports the collaboration of product firms with external actors, required for developing service capabilities (GEBAUER; PAIOLA; SACCANI, 2013; PAIOLA *et al.*, 2013). The collaboration with external companies are usually marked by joint activities of partners exchanging information and resources to co-create value (DYER; SINGH; HESTERLY, 2018). These joint activities require relational assets, which demand significant resources of product firms and can augment operational costs of service provision (FREIJE; DE LA CALLE; UGARTE, 2021; SJÖDIN *et al.*, 2020). The integration through digital systems can address this issue by accelerating the generation and exchange of important information for operations, product features, service provision, and customer processes (OPRESNIK; TAISCH, 2015; RYMASZEWSKA; HELO; GUNASEKARAN, 2017). Thus, in Smart PSSs, inter-firm data integration is seen as the building block to connect collaborating companies and increase value co-creation (OPRESNIK; TAISCH, 2015; STRUYF *et al.*, 2021).

Different actors can be integrated with the product firm to develop and deliver Smart PSSs, in which the literature highlights the suppliers and customers as important actors for integration (BRUSSET; TELLER, 2017; SHAH *et al.*, 2020). According to Shah *et al.* (2020), basic services demand supplier integration, while advanced services require more customer integration. In Smart PSSs, suppliers and product firms can share inventory data in real-time, enabling more precise information for production planning and control and supporting more efficient customization services (BOEHMER *et al.*, 2018; WANG *et al.*, 2021). Suppliers can also be required to directly provide services to the customers, such as remote maintenance and product support (COREYNEN; MATTHYSSENS; VAN BOCKHAVEN, 2016; SHAH *et al.*, 2020). Meanwhile, product firms can also exchange data in real-time with customers, supporting a better condition monitoring of product usage or customer processes, predicting required repairs and

improvements, and obtaining information to develop new solutions (SHAH *et al.*, 2020; ZAMBETTI *et al.*, 2021). Customer data integration allows the provision of some advanced services, such as pay-per-result offerings, in which the product firm monitors the solution condition and guarantees outcomes for the customers (PIROLA *et al.*, 2020; TRONVOLL *et al.*, 2020). In addition, Freije *et al.* (2021) found significant positive associations between customer integration and product innovation capabilities in companies with high levels of servitization, showing that customer integration can be positively related to more innovative outcomes. In this context, we propose the following hypotheses:

***H2:** The digital integration with customers (H2a) and suppliers (H2b) positively moderates the development of Smart PSS in turbulent environments (market and technological turbulence).*

***H3:** The digital integration with customers (H3a) and suppliers (H3b) positively moderates the innovation performance of product firms through Smart PSSs in turbulent environments (market and technological turbulence).*

On the other hand, such integration must overcome barriers related to digitalization (KAHLE *et al.*, 2020; PASCHOU *et al.*, 2020). The data-based activities of digital servitization require reliable connectivity with the internet for data gathering and cloud-based applications. In this context, some advanced features of Smart PSSs require a reliable internet connectivity with efficient internet access, stable internet velocity, mobile network access, and updated IT structure of product firms for proper functioning (ASGHARI; RAHMANI; JAVADI, 2019; LIU *et al.*, 2019; NAIK *et al.*, 2020). As more advanced the service degree and stronger the integration of the solution with external systems, the more the solutions will require reliable network infrastructure for applications based on the internet, cloud, and big data (FRANK *et al.*, 2019; OPRESNIK; TAISCH, 2015; PIROLA *et al.*, 2020). The connectivity with external systems also brings threats related to the lack of cyber security - processes and online systems that aim to identify, control, and protect vulnerabilities related to data transfer within connected systems (PASCHOU *et al.*, 2020). Trust and data privacy are major concerns related to Smart PSSs, as these solutions can capture personal data from customers, which can result in a severe backlash for the product firm if this data is leaked (MARCON *et al.*, 2019;

PASCHOU *et al.*, 2020). Thus, to prevent data leaks without cybersecurity measurements, the companies restrain data to the company's internal servers, limit data access, and avoid external data sharing, which hamper the functioning of more advanced Smart PSSs (TAWALBEH *et al.*, 2020). Thus, we propose the following hypothesis:

***H4:** Network infrastructure issues (H4a) and cybersecurity threats (H4b) negatively moderate the development and delivery of Smart PSSs*

2.2.3 CONCEPTUAL RESEARCH MODEL

Considering the gaps in digital servitization literature and the lack of studies integrating different factors affecting the process, our analysis has a macro contextual approach, as shown in Figure 2.1. This study aims to identify the role of contextual factors in Smart PSS development and its role in increasing product firms' innovation performance. Firstly, we consider contextual conditions for implementing a business model in digital servitization. Secondly, we analyze factors that affect this implementation, considering inter-firm data integration with suppliers and customers and digitalization barriers. We propose hypotheses to test the described factors, as it follows. Thus, this article aims to analyze how digital servitization mediates market and technological turbulence allowing product firms to obtain increased innovation performance and how the inter-firm data integration moderates the process. We also explore the role of digitalization barriers, such as the effect of technology infrastructure issues and cybersecurity threats on digital servitization.

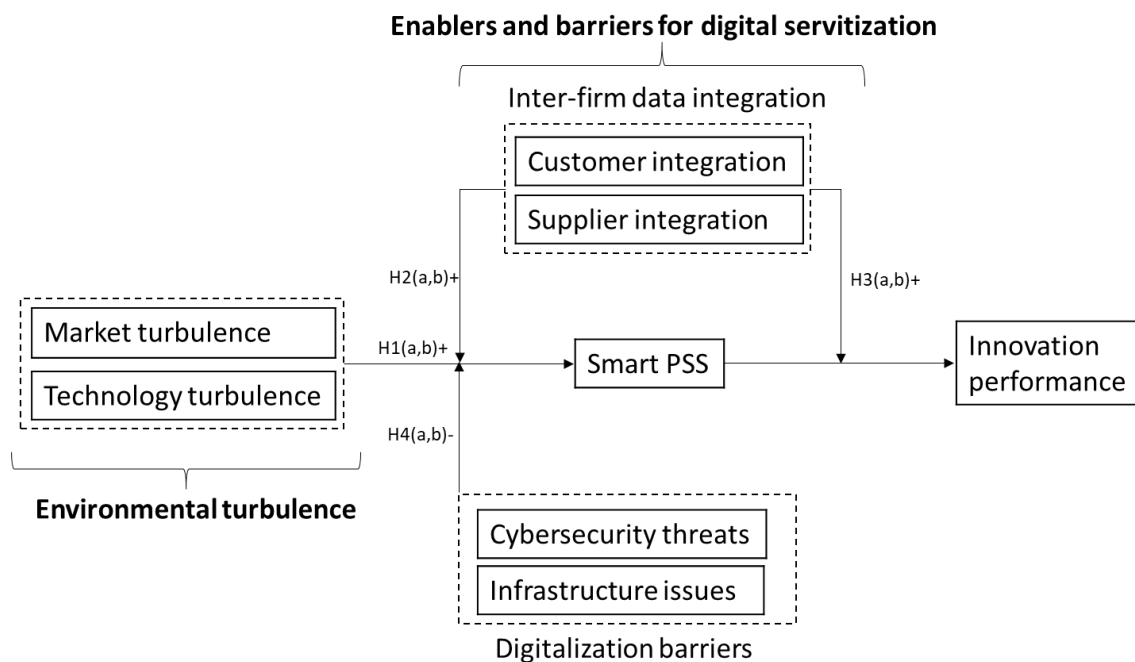


Figure 2.1 Conceptual research model

2.3 RESEARCH METHOD

2.3.1 SAMPLING

We performed a cross-sectional survey of manufacturing enterprises from the southern regional office of the Brazilian Machinery and Equipment Builders' Association (ABIMAQ-Sul). This association was selected due to its trend in digitization initiatives over the country. We also choose this association because it represents one of Brazil's strongest manufacturing sectors and its high potential in developing services through digital technologies. The sample is composed of 233 companies associated with ABIMAQ-Sul. The questionnaires were addressed to the Chief Executive Officers or Operations Directors of the companies, and two follow-ups were sent each after two weeks after the last one. We obtained 102 valid answers, corresponding to a response rate of 43.77%. This considerable response rate is because we had strong support from the ABIMAQ-Sul office, which contacted all associated companies to ask for their participation in the survey. Finally, Table 2.1 details the sample composition and the profile of the respondents.

Table 2.1 Demographic characteristics of the sample

Category	Description	(%)	Category	Description	(%)	
Main industries attended by the product firms of the sample	Agriculture	32%	Company's size	Small (< 100 employees)	40%	
	Other manufacturing	24%		Medium (100-500 employees)	35%	
	Steelworks	22%		Large (> 500 employees)	25%	
	Software and technology	Energy	Transport	Respondent's profile	Managers/directors	74%
					Supervisors	14%
					Analysts	5%
					Other	7%
	Construction	2%	Types of services offered	Smoothing	64%	
	Food products	2%		Adapting	63%	
	Furniture	1%		Substituting	14%	

2.3.2 MEASURES AND SURVEY INSTRUMENTATION

Our study used seven groups of items from our survey as follows: (i) sample characterization – for control variables; (ii) environmental turbulence – for independent variables; (iii) Smart PSS – for dependent and independent variables; (iv) inter-firm data integration – for moderating variables; (v) digitalization barriers – for moderating variables; (vi) innovation performance – for dependent variables; and (vii) digital technologies. First, “*sample characterization*” was used to guarantee our control variables (firm size and revenues) for the models and understand our demographic composition (Table 1). Second, for “*environmental turbulence for the industry*”, we utilized two main variables related to market turbulence [MKT] and technological turbulence [TECH]. We retrieved and adapted these variables from previous studies (i.e., AKGÜN *et al.*, 2007; TSAI *et al.*, 2015; FRANK *et al.*, 2021), which investigated turbulence in product development and servitization fields. Third, for “*Smart PSS*”, we used a set of 11 activities and services related to the digitalization process. These items

were retrieved from the literature (PORTER; HEPPELMANN, 2014; LERCH; GOTSCH, 2015; HERTERICH *et al.*, 2016; RYMASZEWSKA *et al.*, 2017). Fourth, for “*inter-firm data integration*” we considered the level of real-time data integration that product firms have with customers and suppliers. We chose customers and suppliers because they were considered the main collaboration partners in other quantitative research in the service field (AYALA *et al.*, 2017; SHAH *et al.*, 2020). Fifth, for “*digitalization barriers*” we used cybersecurity and IT infrastructure issues as potential restrictions in servitization and digitization literature to develop Product-Service Systems (PASCHOU *et al.*, 2020; PIROLA *et al.*, 2020). Sixth, for “*innovation performance*” we used traditional performance indicators related to innovative capacity in technology and innovation literature (BENITEZ *et al.*, 2021; GÖK; PEKER, 2017). Lastly, for “*digital technologies*”, a set of Industry 4.0 technologies was defined based on Frank *et al.* (2019) work.

Except for sample characterization, a five-point Likert scale was used to capture each of these groups of questions. The five groups (ii to vi) were measured as the implementation level varying from 1 – Not interested in implementing or Very low to 5 – We have advanced implementation or Very High. Thus, the highest degree shows an advanced maturity level on these items or a present barrier or restriction to the enterprise. Additionally, although the digital technologies group was not present in our conceptual research model, we included this group of questions because we used them for endogeneity, common method variance, and robustness tests. Table 2 presents all items used in our regression model.

Table 2.2 Group of variables used in our model

Environmental turbulence	Smart PSS	Data integration	Digitalization barriers	Innovation performance
Market turbulence	Monitoring of performance	Customer data integration	Data restricted to intranet network for security issues	Offerings with innovative products and services
Technological turbulence	Monitoring of product usage	Supplier data integration	Limited data access between sectors due to internal security	New markets entry with the offerings of products and services
	Remote operation		Limited customers' data exchange for protection	
	Autonomous operation		Limited suppliers' data exchange for protection and confidentiality	
	Service demand by apps or platforms		Restrictions to suppliers access our network due to security risks	
	Remote service delivery by apps, platform, or online assistance		Restrictions on access to quality internet	
	Automatized service delivery with AI		Limited connection speed between servers and the operation	
	Autonomous service delivery through connected equipment		Limited access to 3G/4G networks for remote operations	
	Support services to the product		IT infrastructure needs significant upgrades for digital transformation	
	Adapting services			
	Substituting services			

2.3.3 VARIABLES OPERATIONALIZATION, RELIABILITY, AND VALIDITY OF MEASURES

To test unidimensionality, we used the exploratory factor analysis (EFA) using varimax rotation to extract orthogonal components from “*Smart products and digital services*” and “*Digitization barriers*” items. EFA aims to reduce the dimensionality of a given dataset to increase interpretability through construct formation (Hair *et al.*, 2018). The EFA technique enhances the analysis, removes correlated features, and reduces potential overfitting variables (WOLD; ESBENSEN; GELADI, 1987) (Wold *et al.*, 1987). EFA

technique is widely spread in regression works being used for many practices, especially for construct definition in digitization metrics in recent years (e.g., DALENOGARE *et al.*, 2018; BENITEZ *et al.*, 2021). Therefore, we opted for the EFA technique to evaluate the features of each group of variables rather than the variables individually. To this end, we ran two separate EFA procedures for items related to “*Smart PSS*” and “*Digitalization barriers*” subjects. For “*Smart PSS*”, the variable reduction process was composed of 11 variables reduced to three main constructs. To evaluate these constructs, we used three criteria to assess the adequacy of our data to the EFA technique: the Kaiser–Meyer–Olkin (KMO) test, Bartlett’s sphericity test, and the anti-image matrix for Measures of Sampling Adequacy (MSA) (Hair *et al.*, 2018). Upon this, we reached a final set of variables with a good percentage of explanation (i.e., communalities > 0.500) for the constructs, with an exception for substituting services (0.385) which we opted to remain since it is an important service type for servitization in literature (CUSUMANO; KAHL; SUAREZ, 2015; FRANK *et al.*, 2019).

The KMO test result was 0.839 (the generally recommended threshold value is 0.5), and Bartlett's sphericity test showed significance levels lower than 1% ($p\text{-value} < 0.01$). In addition, the anti-image matrix showed a good fitting since all correlation values were above the threshold of 0.5, as suggested by Hair et al. (2018). As previously said, our optimized solution was obtained with three factors. For the three main constructs, we found an explanation of 70.21% of the variance, indicating that these factors account for most of the variables' variance, as shown in Table 2.3. We also assessed the reliability of the constructs by checking Cronbach’s alpha coefficient, which suggested a convergent validity from the main constructs.

Since our main goal is to assess the innovative capacity of enterprises during environmental turbulence in digital servitization, we had to move further and integrate all constructs in a multi-construct. To this end, we elaborated an integrative index containing [SP], [DTSV], and [SERV] constructs representing Smart PSSs. [SP] and [DTSV] represent, respectively, the product and service components enabled by digital technologies. In addition, we add the [SERV] construct, which represents the value added by services in product business models. Therefore, integrative indexes are commonly used for benchmarking purposes in different fields as they allow obtaining single indicators from several items, which together can develop another main activity/goal

(Saary, 2008). We performed this procedure due to the high convergence between digitization and servitization, as suggested in the previous literature (FRANK *et al.*, 2019; KOHTAMÄKI *et al.*, 2020). Therefore, the integrative index of the overall three main constructs from our EFA was calculated as a vector sum of the three axes (each one representing one construct), as represented in equation (1):

$$\text{Smart PSSs} = \sqrt{(\text{SP})^2 + (\text{DTSV})^2 + (\text{SERV})^2} \quad (1)$$

The equation (1) represents the level of implementation of required activities necessary to develop a Smart PSSs. This procedure was already used in Benitez *et al.* (2021) study, also in a digitalization context. Thus, the square root of the three axes results in Smart PSSs, representing an integrative vector index serving as an efficient shorthand to represent the general structure of the constructs. In addition, for “*Digitalization barriers*”, we also performed an EFA procedure. The variable reduction process was composed of nine variables which were reduced to two main constructs. The first construct, [CYBER], represents measures to restrict external access in the company’s internal network infrastructure to prevent data leakages (TAWALBEH *et al.*, 2020). On the other hand, [INFRA] consists of issues due to unreliable network infrastructure, which impedes connectivity access, restrains internet speed, and/or is unable to process all necessary data (ASGHARI; RAHMANI; JAVADI, 2019; LIU *et al.*, 2019). Despite two items presenting low communality values (i.e., 0.379 and 0.436), we chose to remain them since they have high factor loadings values to the overall constructs. Therefore, the KMO test result was 0.780, while Bartlett's sphericity and anti-image matrix tests indicated a good fitting following the thresholds suggested by Hair *et al.* (2018). We found an explanation of 65.51% of the variance for the two main constructs, indicating a good percentage of explanation for our constructs. All results are reported in Table 2.4 and Cronbach's Alpha and eigenvalues.

Table 2.3 EFA procedure results for Smart products and digital services items

Smart Product-Service Systems variables	Factor loadings			Communalities
	Smart Products [SP]	Digital services types [DTSV]	Service types [SERV]	
Monitoring of performance	<u>0.826</u>			0.832
Monitoring of product usage	<u>0.798</u>			0.763
Remote operation	<u>0.864</u>			0.808
Autonomous operation	<u>0.803</u>			0.717
Service demand by apps or platforms		<u>0.502</u>		0.564
Remote service delivery by apps, platform, or online assistance		<u>0.700</u>		0.673
Automatized service delivery with AI		<u>0.834</u>		0.787
Autonomous service delivery through connected equipment		<u>0.829</u>		0.713
Support services to the product			<u>0.788</u>	0.725
Adapting services			<u>0.854</u>	0.756
Substituting services			<u>0.421</u>	0.385
Eigenvalue	5.353	1.300	1.071	
% of variance explained (cumulative)	48.66%	60.48%	70.21%	
Cronbach's alpha	0.900	0.809	0.701	

We proceeded with a single-item construct measure for the other variables in our model related to environmental turbulence and supply chain integration. Wanous and Hudy (2001) and Bergkvist and Rossiter (2007) recommend using single-item constructs when respondents easily and uniformly imagine the item. In the case of performance, we integrated two main variables related to innovative capacity in a two-item construct

representing an $\alpha = 0.935$ of reliability, suggesting goodness of fitness for this construct. Finally, Table 2.5 presents the correlation matrix of the final set of variables used in our analysis. Additionally, this table presents some descriptive statistics, such as mean and standard deviation and the skewness and kurtosis of the data.

Table 2.4 EFA procedure results for Digitalization barriers

Digitization barriers variables	Factor loadings		Communalities
	Cybersecurity restrictions [CYBER]	Infrastructure issues [INFRA]	
Data present only in intranet network due to data security issues	<u>0.614</u>		0.379
Limited data access between sectors due to internal security	<u>0.794</u>		0.637
Customers' data use is limited due to protection restrictions	<u>0.877</u>		0.776
Suppliers' data use is limited due to protection and confidentiality	<u>0.857</u>		0.741
Restrictions to suppliers access our network due to security risks	<u>0.834</u>		0.701
Restrictions on access to quality internet		<u>0.873</u>	0.762
The connection speed between servers and the operation is a limitation		<u>0.859</u>	0.747
Access to 3G/4G networks for remote operations is limited		<u>0.846</u>	0.716
IT infrastructure needs significant upgrades for digital transformation		<u>0.656</u>	0.436
Eigenvalue	3.419	2.477	
% of variance explained (cumulative)	37.98%	65.51%	
Cronbach's alpha	0.855	0.829	

Table 2.5 Correlation matrix and analysis of descriptive statistics

	MEAN	S.D.	Skewness	Kurtosis	1	2	3	4	5	6	7	8	9	10
1 Firm_size (control)	2.201	.775	.187	.187	-									
2 Revenues (control)	3.040	.984	.175	.117	.773**	-								
3 Market turbulence [MKT]	3.460	.817	-.261	.041	.138	.125	-							
4 Technological turbulence [TECH]	3.450	.863	-.081	-.645	.140	.084	.124	-						
5 Cybersecurity restrictions [CYBER]	3.896	1.024	-1.360	2.502	.133	.063	.138	.056	-					
6 Infrastructure issues [INFRA]	2.875	1.253	-.064	-1.220	-.041	-.076	.076	-.096	.124	-				
7 Customer data integration [CUSTOM]	2.132	1.200	.137	-.082	.126	.155	.084	.066	.330**	.245*	-			
8 Supplier data integration [SUPPLIER]	1.980	1.116	.300	.536	.318**	.298**	.184	.040	.178	-.023	.168	-		
9 Smart Product-Service System [Smart PSS]	4.307	1.803	.347	-.010	.260**	.254*	.044	.207*	.174	-.094	.521**	.284**	-	
10 Innovation performance [INNOV]	3.691	1.405	-1.342	1.405	.022	.080	.065	.169	.166	.078	.416**	.084	.411**	-

**p < 0.01; *p < 0.05.

2.3.4 RESPONSE BIAS AND COMMON METHOD VARIANCE

We employed a series of procedures and statistical remedies for potential response bias and common method variance (CMV) as suggested by Podsakoff *et al.* (2012). Concerning procedural remedies, we first pre-tested the questionnaire with key respondents (CEOs and Operations Directors) to validate it and obtain a broader view of our survey instrumentation. We also randomized the order to answer the group of questions and the questions inside each group to prevent possible associations between the variables. For statistical remedies, we employed Harman's single-factor test with exploratory factor analysis to address common method bias. If the total variance extracted by one factor exceeds 50%, common method bias is present in the study (PODSAKOFF *et al.*, 2012). The single factor explained 24.32% of the total variance, indicating CMV is not a concern in our study. In addition, we also performed the marker variable technique to check the common method variance issue. The marker variable technique requires adding a variable from the questionnaire that is expected to be theoretically unrelated to the substantive variables (LINDELL; WHITNEY, 2001). We chose as a marker the variable named "*time frame of company's intention in investing on online traceability*" from another group of questions in our survey that were not utilized in this study. We chose this variable because we understand that the company's intention to invest or not in online traceability will not affect a firm's Smart PSS activities and innovative performance during environmental turbulence. With the addition of this new variable, all results remained stable, which means there was no significant change in the model. Hence, we can conclude that response bias is not a concern in our data set.

2.3.5 ENDOGENEITY AND ROBUSTNESS CHECKS

To test for potential endogeneity, we ran a two-stage least squares (2SLS) regression approach (BASCLE, 2008). We used the group of variable "*digital technologies*", considering Industry 4.0 base technologies (Internet of Things, cloud computing, big data, and artificial intelligence) as instrumental variables since these technologies support the digital capabilities that enhance Smart PSSs (TAO *et al.*, 2018). Through Industry 4.0 base technologies, firms can develop digital services (FRANK *et al.*, 2019; FRANK; DALENOGARE; AYALA, 2019); therefore, IoT, cloud, big data, and AI may be instrumental variables for the development of Smart PSS. Since we related Industry 4.0 base technologies items as instrumental variables for Smart PSS development, we performed a post-estimation procedure in RStudio. We instrumented IoT,

cloud, big data, and AI in [Smart PSS] construct. First, tested the strength of the instruments with the estimators of the first stage of the regression using Stata's first stage. All p-values associated with the models were $p < 0.001$ evidencing strong instruments. After, we assessed Durbin and Wu-Hausman statistics to evaluate the consistency of our estimators. For our data, Durbin and Wu-Hausman showed the hypothesis that the explanatory variables are exogenous could not be rejected (i.e., all p-values > 0.05). Therefore, we obtained for Smart PSS: Durbin = .670 and Wu-Hausman = .688. For the validity of instrumental variables, we assessed the Sargan χ^2 and Basman χ^2 tests. For Smart PSS we found: Sargan χ^2 test p-value = .905 and Basman χ^2 test p-value = 0.920. Thus, the results show that the instruments cannot be invalidated as endogenous.

We also performed a series of robustness checks to ensure that our results were stable. We explored how the results of our regressions analysis might vary using four distinct approaches: (i) removal of control variables; (ii) inclusion of a new construct; (iii) individual analysis from predictors; and (iv) competing model. In the first approach (i) we removed all control variables to ensure that the predictors (MKT, TECH, Smart PSS, CUSTOM, SUPPLIER, CYBER, and INFRA) are not artifacts of the control variables. We included a new construct named "Vertical integration" for the second approach, composed of PLCs (Programmable Logic Controllers), SCADA, MES, and ERP. Since this construct was already theoretically validated in the literature (FRANK *et al.*, 2019), we expected to find significant effects from the relationship of vertical integration with Smart PSS because internal integration is paramount for enterprises to develop internal capabilities to support their Smart Product-Service Systems (SHAH *et al.*, 2020; SKLYAR *et al.*, 2019). The results showed a significant direct effect of vertical integration construct, confirming the link between automation technologies and Smart Product-Service Systems, supporting the main findings of this study. In the third stage, we assessed the individual relationship of our predictors with Smart PSS and INNOV, excluding all predictors but one, and overall, the results remained stable. Finally, for competing model analysis, we changed [Smart PSS] with [CUSTOM] and [SUPPLIER] constructs, and we did not find any interaction effect, showing that our models are not overfitted.

2.3.6 DATA ANALYSIS

We used a set of hierarchical OLS regression models to test our hypotheses in RStudio. First, we assessed all models only with the presence of the control variables (firm size and revenues).

Second, we tested all models with the inclusion of the independent variables to check their direct effects on the models. Third, we included the moderating effects (multiplications) in our third stage to assess the potential interaction effects amid our variables. Lastly, to assess the mediation effect, we utilized Hayes' suggestion (HAYES, 2017) to calculate the indirect effects of Smart PSS (as mediator) in environmental turbulence (MKT and TECH) and INNOV relationship. We standardized the independent and moderating variables for all these procedures using a mean-centering (Z-score). Our final model contains seven independent variables, ten interaction effects, two dependent variables, and two control variables.

We also tested to confirm the assumptions of linearity and homoscedasticity for all independent and dependent variables. We analyzed collinearity by plotting the partial regressions for the independent variables, while homoscedasticity was visually examined in plots of standardized residuals against a predicted value. All these requirements were met in our dataset for regression analysis. Moreover, we checked the normality of our data and all values were between the thresholds of ± 2.58 ($\alpha = 0.01$), as previously shown in Table 5, suggesting this is not a concern in our OLS estimations. Finally, we evaluated the multicollinearity issue for our independent variables, as suggested by Hair *et al.* (2018). In multicollinearity, regression estimates are unstable and have high standard errors. Our results indicate a low VIF (< 3.0) for all variables, far away from the maximum allowed threshold of 10 (HAIR *et al.*, 2018).

2.4 FINDINGS

We ran three independent models in a hierarchical structure for each model to present our results. For "Part 1" we ran three hierarchical stages for Smart PSS where: (i) in the first model we only included control variables; (ii) in the second model, we included all independent variables (MKT, TECH, CUSTOM, SUPPLIER, CYBER, and INFRA); and (iii) in the third model we included all moderating relationships. In "Part 2" we also ran three hierarchical stages for INNOV: (i) control variables; (ii) inclusion of MKT and TECH; and (iii) inclusion of Smart PSS. Finally, for "Part 3" we ran three hierarchical stages for INNOV as follows: (i) control variables; (ii) inclusion of CUSTOM, SUPPLIER, and Smart PSS; and (iii) inclusion of moderating effects of CUSTOM and SUPPLIER. In all models, we did not report the first model (i.e., the results of control variables) since our main goal was to evaluate the overall picture of our model by including independent and moderating variables.

As shown in Table 2.6, all models, excepting Model 2 for INNOV ($F = 1.049$; $p = 0.386$; Change in $R^2 = 0.115$; $p = 0.212$) were significant at $p < 0.01$, showing significant R^2 Changes (at least below 0.05) in all stages in our hierarchical procedures. As a result, for the final step of each model (Model 3) we had: Smart PSS (Part 1: $F = 5.509$, $p < 0.001$), INNOV (Part 2: $F = 4.567$, $p = 0.001$), and INNOV (Part 3: $F = 5.285$, $p < 0.001$). Unstandardized coefficients are reported in Table 6 since all scales were standardized with Z-scores because they represent a standardized effect (Goldsby *et al.*, 2013).

Regarding environmental conditions for digital servitization, in Part 1 of Table 2.6 we found a strong influence of TECH on Smart PSS ($B = 0.408$, $p = 0.012$), but none for MKT on Smart PSS. For digitalization barriers, we found a negative direct association with INFRA ($B = -0.383$, $p = 0.014$) on Smart PSS development but no direct association of CBS. Regarding H4, the moderating effect of INFRA was negative for TECH ($B = -0.368$, $p = 0.033$), and no association was found between INFRA and MKT. On the contrary, we found that CBS positively moderates MKT ($B = 0.409$, $p = 0.041$), but no association in TECH was found. However, by analyzing the plotted slopes (Appendix A), we can conclude that when there are low cybersecurity restrictions, firms tend to develop more Smart PSS. Thus, we partially support H4, bringing evidence of the association of INFRA in TECH and CBS in MKT.

Concerning the inter-firm data integration for Smart PSS development, we found direct statistical associations of CUSTOM ($B = 1.044$, $p < .001$) and SUPPLIER ($B = 0.263$, $p = 0.094$) for the development of Smart PSS, but we found different patterns of these variables when moderating environmental turbulence (H2). CUSTOM positively moderates the development of Smart PSS in TECH ($B = 0.270$, $p = 0.079$), but negatively moderates in MKT ($B = -0.365$, $p = 0.048$). However, the slopes (Appendix A) indicate that enterprises develop more Smart PSS during market turbulence when high customer integration occurs. Thus, we can confirm H2a. For SUPPLIER, we only found a positive moderation in MKT ($B = 0.327$, $p = 0.052$), thus only partially supporting H2b and consequently partially supporting H2.

Table 2.6 Results of the regression analysis ^(a)

Independent variables	Part 1		Part 2		Part 3	
	Smart PSS		INNOV		INNOV	
	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3
Firm_size (control)	.251	.037	-.244	-.338	-.262	-.290
Revenue (control)	.042	.180	.235	.152	.118	.158
Market turbulence [MKT]	-.083	-.276 (p = .083)	.059	.067		
Technological turbulence [TECH]	.247	.408 (p = .012)	.237 (p = .098)	.134		
Customer data integration [CUSTOM]	.950 (p = .000)	1.044 (p = .000)			.385 (p = .010)	.477 (p = .002)
Supplier data integration [SUPPLIER]	.282 (p = .078)	.263 (p = .094)			-.032	-.059
Cybersecurity restrictions [CBS]	-.037	-.007				
Infrastructure issues [INFRA]	-.350 (p = .025)	-.383 (p = .014)				
Smart Product-Service Systems [Smart PSS]				.577 (p = .000)	.409 (p = .009)	.349 (p = .024)
MKT x CBS		.409 (p = .041)				
MKT x INFRA		.071				
TECH x CBS		-.206				
TECH x INFRA		-.368 (p = .033)				
MKT x CUSTOM		-.365 (p = .048)				
MKT x SUPPLIER		.327 (p = .052)				
TECH x CUSTOM		.270 (p = .079)				
TECH x SUPPLIER		.170				
Smart PSS x CUSTOM						-.256 (p = .014)
Smart PSS x SUPPLIER						.054
F-value	7.552 (p = .000)	5.509 (p = .000)	1.049 (p = .386)	4.567 (p = .001)	5.899 (p = .000)	5.285 (p = .000)
R ²	.394	.509	.041	.192	.235	.282
Adjusted R ²	.342	.417	.002	.150	.195	.229
Change in R ²	.319 (p = .000)	.115 (p = .017)	.031 (p = .212)	.151 (p = .000)	.225 (p = .000)	.047 (p = .049)

^(a) Unstandardized beta coefficients are reported since the main variables were standardized before regression

Regarding inter-firm data integration for increased innovation performance (H3), in Part 3 we have both a direct association of CUSTOM on INNOV ($B = 0.477$, $p = 0.002$) and Smart PSS on INNOV ($B = 0.349$, $p = 0.024$), but a negative moderation effect of CUSTOM in Smart PSS ($B = -0.256$, $p = 0.014$). However, our slope result suggests that this relationship only occurs when the enterprise has a high level of data integration with its customer. When there is a moderate level of data integration, the benefits are also positive, suggesting a potential curvilinear relationship (i.e., in short, and medium terms, it is advantageous, while in the long run, it is disadvantageous). Therefore, we can only partially support this hypothesis (H3a) since more evidence is needed. We found no evidence for H3b.

To evaluate our H1 (i.e., mediation effect from Smart PSS on environmental turbulence and INNOV relationship), we followed Preacher and Hayes's (2008) bootstrapping approach to assess the indirect effects of the relationships. We adopted the PROCESS analysis developed by Hayes (2017) to check our hypothesis (H1) associated with mediation. PROCESS analysis allows for a bootstrapping procedure to examine the conditional indirect effects, a more effective procedure than Sobel's z test to test for mediation effects (Zhao *et al.*, 2010). We set 5,000 bootstrap samples as Preacher and Hayes (2008) suggested. Table 2.7 presents the estimates, standard errors, significance level, and corresponding lower (LLCI) and upper level (ULCI) confidence intervals.

Our results show that H1b (i.e., Smart PSS mediation between technological turbulence and INNOV) is supported. For H1b, we found a complete mediation since the direct effect of TECH was not significant. Furthermore, we did not find any issues in the 95% confidence intervals since the bootstrapped indirect effect does not fail to be within the lower and upper levels. On the other hand, we did not find mediation effects of Smart PSS between MKT and INNOV, which means that H1a was not supported.

Table 2.7 Indirect effects (bootstrapping outcome)

Interactions	Bootstrap outcome			95% confidence		Total and direct effects	Sig.	Conclusion
	Mean	SD	Sig.	LLCI	ULCI			
MKT -> Smart PSS -> INNOV	.025	.055	.000	-.086	.134	TOTAL EFFECT DIRECT EFFECT	.517 .609	No mediation
TECH -> Smart PSS -> INNOV	.114	.059	.000	.007	.242	TOTAL EFFECT DIRECT EFFECT	.089 .346	Complete mediation

As a final remark, we also submitted the regression models to statistical power analysis, as proposed by Cohen et al. (2003). We estimated the statistical power of the partial coefficients using Cohen's f^2 estimation for the predictors and the range of effects, where below 0.15 is a small effect, between 0.15 and 0.35 a medium effect and a large effect when higher than 0.35 (Cohen et al., 2003). From all significant effects in the three models, we obtained overall medium and some large effects, suggesting that our results follow the minimum statistical power necessary for regression models (Cohen et al., 2003).

2.5 DISCUSSIONS

Our findings show that product firms can obtain increased innovation performance in technological turbulence contexts through Smart PSSs. In industries where product technology changes continuously, the integration of services in product offerings supports the adaptation of product firms to new technologies. This indicates the two-fold relationship between digitalization and servitization. The application of digital technologies in products enables the provision of advanced services (FRANK *et al.*, 2019), while the service orientation of PSSs supports the adoption of digital technologies, resulting in more innovative solutions. Thus, we bring statistical evidence for conceptual propositions of the literature regarding services and technology adoption (CUSUMANO; KAHL; SUAREZ, 2015; FRANK *et al.*, 2019). However, we did not confirm the influence of market turbulence on Smart PSSs as suggested by the literature. This can be explained by the characteristic innovation activities in Brazil. Frank *et al.* (2016) found that most product firms in the country have a technological acquisition orientation of innovation activities, with the acquisition of equipment, machinery and software, instead of market-orientation with internal R&D activities. This suggests that in this context, product firms expect more established technologies to apply in their solutions, and use services with their customers for adaptations. This strategy brings fewer innovation outcomes than a market-orientation, especially for product firms within global markets (FRANK *et al.*, 2016). However, both product firm and customer assume lower risks in the development of new solutions.

In this context of high technological turbulence, the confirmation of H4a shows a negative association between internet infrastructure issues and the development of Smart PSSs, suggesting that product firms have been facing problems with internet connectivity in digital servitization. With the growing demand for internet-based applications, the lack of reliable

network infrastructure for internet connectivity is a barrier for product firms. Low internet access can affect all involved parties for value creation, impeding the required data capture, transfer, and analysis for more advanced capabilities in digital servitization. Thus, this issue must be addressed at a service ecosystem level, as developing a reliable internet infrastructure depends on many actors, including governmental institutions and industry associations (NAIK *et al.*, 2020; PASCHOU *et al.*, 2020). In addition, in high market turbulence contexts, the results show that in the presence of cybersecurity threats, the development of Smart PSSs decreases. As previously indicated (MARCON *et al.*, 2019), the fear of data leakage remains an important barrier for digital servitization, discouraging product firms to invest in internet-based solutions. Since this issue occurs both in emerging and developed countries (MARCON *et al.*, 2019; PEILLON; DUBRUC, 2019), it calls for further attention in the Smart PSSs design. Product firms must analyze the trade-offs between centralized and decentralized data activities. In addition, although cloud applications are more effective, applications based on embedded software in the product with limited access to external systems can be an alternative for product firms to overcome this issue (PORTER; HEPPELMANN, 2014).

Regarding inter-firm data integration, we confirmed supplier data integration positively moderates Smart PSSs development in market turbulence, but no association in technological turbulence or with innovation performance was found. We expected to find a positive association, as environments with high technological turbulence demand product firms to constantly learn changing technologies (HANVANICH; SIVAKUMAR; HULT, 2006), which can be supported by knowledge sharing with suppliers (AYALA *et al.*, 2017; SHAH *et al.*, 2020). We relate this issue with Oosterhuis *et al.* (2011) findings, which show that buyer-supplier relationships can negatively affect performance when both actors have distinct perceptions of technological uncertainty. Similarly, Wang *et al.* (2016) found that the degree of common knowledge between buyers and suppliers has an inverted u-shaped association with increased product co-development in emerging markets, also evidencing that when the partner has lower or higher knowledge than the focal firm, the increased integration is generally not followed by increased performance. Considering this knowledge gap, combined with the technological acquisition orientation of innovation activities in Brazil (FRANK *et al.*, 2016), we assume that product firms receive suppliers' support mostly to respond to demand fluctuations in market turbulence, with a lower engagement of suppliers more innovative solutions. In addition, our sample is mainly composed by product firms that offer smoothing

and adapting services (Table 2.1), which are more complementary to the product value. Ayala *et al.*, (2017) suggest that in this context, the product firms probably design the solution independently, integrating suppliers mostly in the execution phase. However, more studies are required to understand the suppliers' role in digital servitization.

Moreover, our findings show a complex relationship between customer data integration and innovation performance through Smart PSSs. In both market and technological turbulence, customer integration supports the development of Smart PSSs, but only in the latter, a significant association was found with innovation performance. The slopes indicate that innovation performance can be increased with customer integration, but to a certain level. According to Wang *et al.*, (2021), servitization can lead product firms to become over embedded in existing customer relationships, demanding relational assets that absorb resources and capabilities that could be used to seize new market opportunities. However, we expected a positive association, as the authors focused on relational capabilities while our study concerned customer data integration. A possible explanation is that customer data integration can support the development of new solutions, but product firms still require investments in relational assets to reach new customers. Thus, the more they spend resources building stronger relationships with the customer, the more they restrain new opportunities, even with the support of digital systems. In conclusion, we can confirm that customer data integration is required to develop Smart PSSs and supports the development of more innovative solutions in existing markets. However, product firms must find an optimal level of relationship to not prevent new market opportunities.

2.6 CONCLUSIONS

Our article brings statistical evidence for important gaps in the digital servitization literature. Despite studies relating servitization with market turbulence, we only found Smart PSSs mediating technological turbulence for increased innovation performance. However, this finding can be related to the context of the analyzed sample. Even though we could partially confirm the positive effect of inter-firm data integration on digital servitization, our findings corroborate the literature by showing a complex relationship between customer integration and innovation performance in servitized contexts. These findings have theoretical and practical contributions, as follows.

2.6.1 THEORETICAL CONTRIBUTIONS

The results bring advancements for understanding the digital servitization journey by identifying the effect of some environmental factors on the process and its effect on innovation performance. Firstly, we identify some contexts in which Smart PSSs bring more innovative outcomes for product firms. Secondly, we complemented recent findings on these topics by considering a broader perspective. Shah et al. (2020) indicate supplier and customer integration supporting, respectively, basic and advanced service provision. In our case, suppliers' integration was positive for market turbulence, while customer integration is associated with market and technological turbulence. Thus, we can extend their findings by showing that the technological change encourages product firms to innovate their offerings in collaboration with customers. At the same time, suppliers support production planning by addressing the changes in customer preferences of existing solutions. We also complement the findings of Wang et al. (2021) by showing that inter-firm data integration with customers still does not solve the issue of spending relational resources that prevent firms from seizing new opportunities. In technological turbulence, there is an optimal level of customer integration for increased innovation performance, in which increased integration can decrease innovative outcomes. Thus, our results bring support to the development of conceptual models that explain the servitization journey of product firms.

2.6.2 PRACTICAL CONTRIBUTIONS

Firstly, we bring empirical evidence on digitalization barriers negatively affecting the development of Smart PSSs. This finding highlights the need of product firms to address this issue and to combine efforts with other actors, as these barriers call for the action of different actors, including governmental institutions and other industrial sectors. Our findings also support managers in the inherent "make-or-collaborate-or-buy" decisions of digital servitization (KOHTAMÄKI *et al.*, 2019). We identified some of the factors in which the process is associated with more innovative outcomes when integrated with external actors. Product firms in industrial sectors with continuous change in technology will benefit by integrating customers with Smart PSSs, co-developing more innovative solutions. In addition, the relationship between customer integration and innovation performance calls for product firms to strategically align inter-firm data integration and relational assets with their desired

objective in terms of firm performance. Although more research is needed, the findings on suppliers' integration also provide product firms to understand their role in digital servitization.

2.6.3 LIMITATIONS AND FUTURE STUDIES

We chose to focus on customer and supplier integration to address open gaps in the role of inter-firm data integration in digital servitization. We found that customer data integration can be negatively associated with innovation performance. The data integration should support product firms to obtain insights to improve their business, also supporting the communication channels and relationships with the customer. We suggest further studies to analyze the relationship between inter-firm data integration and inter-firm collaboration to understand how they complement each other. In addition, the literature has been increasingly considering a need to widen the perspective on a service ecosystem level. Although customers and suppliers are considered the most important actors to provide value in digital servitization (SHAH *et al.*, 2020), a service ecosystem perspective requires the consideration of other actors and institutions that directly and indirectly affect the business model implementation of digital servitization. Moreover, our sample is composed of product firms within the machinery industry. Other manufacturing sectors must be considered to compare the patterns and develop guiding models of the servitization journey to product firms. Lastly, we focused on environmental factors affecting digital servitization and inter-firm data integration, not investigating such relationships with different types and levels of services, nor the digitalization degree of product firms. Future studies could include these factors to complement our findings.

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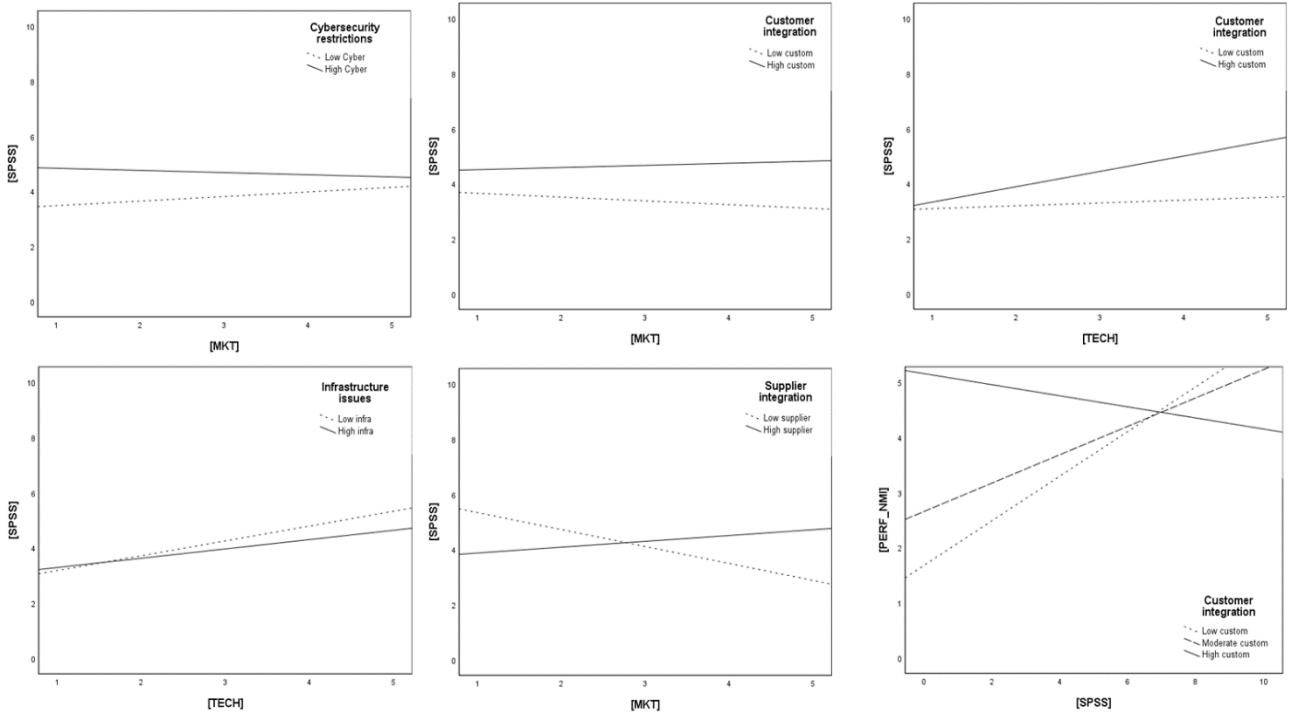
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APPENDIX A – SLOPES FOR MODERATING EFFECTS



3 ARTICLE 2 – MULTICHANNEL DIGITAL SERVICE DELIVERY AND SERVICE ECOSYSTEMS: THE ROLE OF DATA INTEGRATION WITHIN SMART PRODUCT-SERVICE SYSTEMS

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Abstract:

Services for Smart Product-Service Systems (PSS) business models can be delivered through multiple digital channels like smart products, cloud systems, and workers enhanced by virtually augmented systems. Since these channels are data-intensive dependent, they usually require data sources from the company's service ecosystem. Prior studies have shown how to build network capabilities for Smart PSS, but little is known about the extensive integration of data in such service ecosystems. We aim to understand how multichannel digital services can be supported by the integration of real-time data from service ecosystems to provide Smart PSS business models. Using the organizational information-processing theory, we consider the integration of data from three ecosystem actors (other business units, suppliers, and customers) and analyze how such data sources can support the use of these digital technologies in three types of Smart PSS business models. We examine these relationships through regression analyses based on a survey of 92 manufacturers, providing a typology of different Smart PSS business models in the ecosystem. Our study enlightens how data flows through the ecosystem actors to support Smart PSS business models. Practitioners and scholars can learn how to treat Smart PSS according to the specific business models to be implemented and how to combine digital technologies with data integration channels in the service ecosystem. Moreover, we show how this combination of digital transformation and Smart PSS help expand the organizational information-processing theory in the innovation ecosystems' domain, also providing a new vein of research to the digital servitization literature.

Keywords: Smart Product-Service Systems (PSS); Digital Servitization; Digital Ecosystems; Digital technologies.

3.1 INTRODUCTION

The increasing use of digital technologies has enabled the digital transformation of manufacturing business models in internal operations and the provision of Smart Product-Service Systems (PSSs) (BRESCIANI *et al.*, 2021; FRANK *et al.*, 2019; MEINDL *et al.*, 2021). The business model of Smart PSSs comprises bundles of products and services with digital and smart capabilities, which can create, deliver and capture value, as the delivery system of the Smart PSSs connects manufacturers, customers, and other external actors through the internet of things concept (GARCIA MARTIN; SCHROEDER; ZIAEE BIGDELI, 2019; MARCON *et al.*, 2022; PASCHOU *et al.*, 2020). These business models can focus on complementary digital services that support the products or more advanced servitized solutions that provide digital customization of the product or the offering of pay-per-use or pay-per-results Smart PSSs (FRANK *et al.*, 2019).

Manufacturing companies can use three main different and complementary digital channels for the service delivery system in Smart PSSs (PASCHOU *et al.*, 2020; VALENCIA *et al.*, 2015): services embedded in the product offering as smart products (BEVERUNGEN *et al.*, 2019; KAHLE *et al.*, 2020); services delivered through independent cloud systems supported by advanced digital technologies such as big data analytics and artificial intelligence that complements products (MAGLIO; LIM, 2016; ZHENG *et al.*, 2018); or services delivered through service workers enabled by virtually augmented systems, like augmented reality and similar technologies (DORNELLES; AYALA; FRANK, 2022; MAGLIO; KWAN; SPOHRER, 2015; MASOOD; EGGER, 2020). The use of these three digital channels for service delivery (smart products, cloud systems, and virtually augmented systems) requires the generation and streaming of data throughout different external actors to the company that configures a service ecosystem (BABICEANU; SEKER, 2020; BENITEZ; AYALA; FRANK, 2020; KOHTAMÄKI *et al.*, 2019). The data integration among different actors of the service ecosystem can bring several benefits to the development and delivery of Smart PSSs, and provide business insights that can enhance the servitization process of manufacturing companies (BRESCIANI *et al.*, 2021). Rather than just participating in PSS development, the service ecosystem can also support digital technologies by providing rich contextual data for service provision, enabling more advanced features based on big data and artificial intelligence (DE LUCA *et al.*, 2021; OPRESNIK; TAISCH, 2015).

The literature has focused the attention on how to involve the different ecosystem actors (e.g., SKLYAR *et al.*, 2019), how to configure such ecosystems (e.g., TRONVOLL *et al.*, 2020), how to combine the ecosystem actors' capabilities (e.g. MARCON *et al.*, 2022), and what kind of value the ecosystem can provide (e.g., GARCIA MARTIN; SCHROEDER; ZIAEE BIGDELI, 2019). However, little is known about the different ways ecosystem actors integrate data in the offering of Smart PSS solutions. While the theory has enlightened the role of such importance of ecosystems for creating Smart PSS solutions, scholars focused on the actor's role without analyzing the sources of data integration to deliver such kinds of solutions in Smart PSSs. As previously shown by Kahle *et al.* (2020), digital ecosystems face several challenges, and one of them is being able to identify and understand how data can be shared and integrated among the main actors of the ecosystem. Data integration is not a trivial issue in digital service ecosystems since the different actors may face challenges like social demands for data protection (BRESCIANI *et al.*, 2021; OPRESNIK; TAISCH, 2015), cybersecurity treads (PASCHOU *et al.*, 2020), or digital surveillance problems (GRUBIC; PEPPARD, 2016), that may create barriers for the development of Smart PSS solutions. Therefore, service ecosystems also need to consider actors' involvement in a data integration perspective to deliver digital services in Smart PSS business models when social and technological restrictions are present (KAHLE *et al.*, 2020). In this sense, the following research question arises: *to what extent do different service ecosystem actors contribute through data integration with servitized companies to support the multi-channel digital service delivery in Smart PSS business models?*

We build our study following the organizational information-processing (OIP) theory applied to the digital servitization and service ecosystem perspectives. We propose three main types of service delivery through digital channels (service embedded into smart products, cloud systems, and virtually augmented systems), which can be supported by external real-time data from three main ecosystems actors (other business units, suppliers, and customers) previously explored by Benitez *et al.* (2022). The aim is to analyze whether these actors support the multi-channel digital service delivery through data integration to enhance different Smart PSS business models. We conducted a survey with 92 companies from the machinery and equipment sector and analyzed the collected data using regression models with interaction effects. Our results show different digital technologies applications with data integration of a service ecosystem to provide each of the three Smart PSS business models investigated. We also show some limitations in external data integration. The main contribution is that the

findings show how service delivery through digital technologies is supported by external data sources, providing a typology of different Smart PSS arrangements in the ecosystem. We highlight the need to treat Smart PSS according to the specific business models that manufacturing companies want to implement since each will require different approaches between digital technologies and data integration channels with the service ecosystem. We also show how these configurations help expand the OIP perspective of digital servitization. Consequently, our study contributes to the literature by showing what data and from which actor of the service ecosystem is relevant to building different Smart PSS business models. Rather than just considering actors' capabilities and roles - which is largely explored in the digital servitization literature (MARCON *et al.*, 2022) – we provide details on digital technologies and data characteristics. Such contribution is aligned with prior claims from Kahle *et al.* (2020) for more detailed and technology-oriented research in the ecosystem research field. Our study shows that digital servitization is not just about collaboration and interaction among the ecosystem actors but also needs data sharing and integration, creating bigger challenges for manufacturing companies (FRANK *et al.*, 2019). Thus, we provide further discussions and implications for practitioners and scholars that may want to build the architecture for Smart PSS through service ecosystems.

3.2 THEORETICAL BACKGROUND

3.2.1 MULTICHANNEL DIGITAL SERVICE DELIVERY IN SMART PSS BUSINESS MODELS

The 'smart' capability of Smart PSS is obtained from the intensive use of general-purpose (or base) digital technologies, such as the Internet-of-Things (IoT), cloud computing, big data analytics, and artificial intelligence (FRANK; DALENOGARE; AYALA, 2019). Such technologies generate smart systems that can respond to the environment and exchange information with surrounding objects and people, especially with virtual tools, enabling more innovative service delivery through multiple channels (TAO *et al.*, 2018; ZHENG; WANG; CHEN, 2019). Service channels represent how companies and customers exchange knowledge and resources to create value (ELORANTA; TURUNEN, 2016; FRANK *et al.*, 2019; SOUSA; AMORIM, 2018). Digital servitization establishes digital channels to deliver services easily connected with smart capabilities, improving the efficiency and effectiveness of service provision and communication with customers (ARDOLINO *et al.*, 2017; MARCON *et al.*, 2022; PASCHOU *et al.*, 2020). The digital servitization literature shows that services are

delivered through at least three different but complementary digital channels, i.e., smart products (BEVERUNGEN *et al.*, 2019; KAHLE *et al.*, 2020), cloud-based systems (FRANK *et al.*, 2019; PIROLA *et al.*, 2020), and virtually augmented systems (DALENOGARE *et al.*, 2019; DORNELLES; AYALA; FRANK, 2022), as explained next.

Smart products are products composed of physical, smart, and connectivity components that enable digital capabilities to deliver different automated services (PORTER; HEPPELMANN, 2014). Through sensors and data collection, products can be monitored regarding their condition and operational usage (KAHLE *et al.*, 2020). When connected with embedded software, a smart product can control its functions through a personalized user experience. With analytical algorithms, smart products can be optimized, enhancing their performance with predictive diagnostics. With more advanced artificial intelligence algorithms, smart products can be autonomous, self-coordinating operations with self-diagnosis (PORTER; HEPPELMANN, 2014). According to Beverungen *et al.* (2019), smart products are boundary objects of other resources and activities that allow cross-boundary data and information transfer, making them a platform for digital services. Thus, smart products provide context awareness and self-service embedded functionalities to service consumers without requiring intervention from service providers (BEVERUNGEN *et al.*, 2019; WUENDERLICH *et al.*, 2015). A case in point is digital pay-per-usage solutions, such as Car-to-go with connected cars and Michelin with its pay-by-the-mile lease of tires with embedded sensors (FRANK *et al.*, 2019).

Cloud-based systems are provided by web platforms and online applications and consist of purely digital channels for service delivery (LERCH; GOTSCH, 2015). Through cloud platforms, manufacturing companies can deliver more customized and advanced services based on intelligent algorithms that would be limited to local data sources in solely smart products (BEVERUNGEN *et al.*, 2019; LEE; KAO, 2014). Through online applications, manufacturing companies can provide additional information about the product to the customer, improving their value perception and enhancing product sales (FRANK *et al.*, 2019). The use of cloud-based online services also supports solution personalization by the user once digital services have a low marginal cost to be executed (OPRESNIK; TAISCH, 2015; VALENCIA *et al.*, 2015). Thus, the use of cloud platforms enables the management of PSS by allowing easy and remote access to the solution. In addition, when business intelligence techniques are applied, new market demands can be identified by the manufacturing company (MAGLIO; LIM, 2016;

OPRESNIK; TAISCH, 2015). Also, cloud platforms allow for product integration with other systems of products and digital services (PAPERT; PFLAUM, 2017; PORTER; HEPPELMANN, 2014). This is the case of Siemens' MindSphere platform, an open-source platform that hosts digital services based on data collection and analysis from connected objects of industrial processes (HERTERICH; UEERNICKEL; BRENNER, 2016). Thus, cloud services enable advanced services related to different systems of products and services, providing additional value to existing offerings (FRANK *et al.*, 2019; ZHENG *et al.*, 2018).

The third channel of digital service delivery in Smart PSSs is through digital tools that support service workers' operations (DORNELLES; AYALA; FRANK, 2022; FRANK *et al.*, 2019; MEINDL *et al.*, 2021), which we call *virtually augmented systems*. The use of virtual technologies can enhance the field service provision by remotely aiding field service operators, thus optimizing existing services (HERTERICH; UEERNICKEL; BRENNER, 2016). In this case, virtual technologies are considered the key tool for providing services (MASOOD; EGGER, 2020; ZUBIZARRETA; AGUINAGA; AMUNDARAIN, 2019). Augmented reality allows service operators to reach real-time digital content with high levels of interaction, perceiving the physical world while simultaneously accessing information. In these dynamics, the operator gains knowledge and skill improvement, enabling the provision of services with increased efficiency (DORNELLES; AYALA; FRANK, 2022; LONGO; NICOLETTI; PADOVANO, 2017; MASOOD; EGGER, 2020). Besides, virtual reality is considered a powerful tool for developing new products, especially in the early design stages. Manufacturing companies can perform several simulations to validate product maintainability, enhancing its performance in the whole life cycle (GUO *et al.*, 2018). Moreover, virtual reality can help service workers to envision how the service should be executed, such as in cases of customized furniture projects in which the service worker can simulate the customer spaces and anticipate what the environment will look like (DORNELLES; AYALA; FRANK, 2022; FRANK *et al.*, 2019).

The use of *smart products*, *cloud systems*, and *virtually augmented systems* supports digital services in different types of PSS business models (FRANK *et al.*, 2019; MASOOD; EGGER, 2020; VALENCIA *et al.*, 2015). PSS business models integrate services into the product offering to increase the value delivered to the customer. Therefore, they are considered product-oriented business models and are differentiated from service-oriented business models in which the product firm offers services, such as management consulting and logistics, as a stand-alone

solution from the product (VISNJIC; RINGOV; ARTS, 2019). PSS business models consider services that can complement a product's functions or substitute its sale. Cusumano, Kahl, and Suarez (2015) called these business models *smoothing*, *adapting* (both complementary services), and *substituting* services. The manufacturing company can offer basic services that only "smooth" the product sale or usage without changing its functionality in complementary services. These so-called *smoothing services* consist of maintenance, technical support, and basic product training. In more advanced complementary services, the manufacturing company will change or expand the product's functionalities, adapting its use for a specific environment or purpose. These *adapting services* are represented by major customizations, dedicated training or consulting for new product applications, and integration of the product with other solutions, which requires an alteration of the current system design. In *substituting services*, the manufacturing company starts selling the product as a service, replacing its purchasing, and changing its ownership. Examples of substituting services are data processing services, software as a service, and pay-per-usage solutions such as the "Power by the Hour" of Rolls Royce or the pay-per-print solution of Canon (ARDOLINO *et al.*, 2017). Frank *et al.* (2019) have shown that different levels of digitalization can support these three types of PSS business models, and all of them can create value for both the customer and the organizational processes. We aim to contribute to this stream by considering not only the data integration with customers, as they did, but also the relevance of other actors of the ecosystem as real-time data providers to increase the value of these types of Smart PSS business models.

3.2.2 ORGANIZATIONAL INFORMATION-PROCESSING THEORY IN SERVICE ECOSYSTEMS FOR SMART PSS

The Smart PSS literature has acknowledged the central role of inter-firm collaboration within service ecosystems to provide Smart PSS (KOHTAMÄKI *et al.*, 2019; SKLYAR *et al.*, 2019b). Most of the studies have focused their attention on the contribution of ecosystem actors to digital competencies in the provision of Smart PSS solutions (KAHLE *et al.*, 2020; MARCON *et al.*, 2022; SKLYAR *et al.*, 2019b) and strategic choices related to organizational configuration, partner selection and make-or-collaborate-or-buy decision (BUSTINZA *et al.*, 2019; KOHTAMÄKI *et al.*, 2019). A second stream has considered the service ecosystem from an information systems perspective (ARDOLINO *et al.*, 2017; OPRESNIK; TAISCH, 2015). This stream addresses different technical factors of ecosystem actors' integration, including interoperability, data and information integration challenges, and systems requirements for the

provision of integrated solutions (AGOSTINHO *et al.*, 2016; ANDRES; POLER; SANCHIS, 2021; FIGAY *et al.*, 2012; PAN *et al.*, 2021). This second stream has focused mainly on the technical aspects of information integration, while the managerial studies have given very little attention to such information aspects in service ecosystems. Several studies have stressed this perspective as a keystone for the development of digital servitization (OPRESNIK; TAISCH, 2015; PASCHOU *et al.*, 2020; TRONVOLL *et al.*, 2020). Nonetheless, the literature lacks evidence on this the operationalization of data integration since most of the studies have been built around managerial issues without deepening into the technological requirements (MARCON *et al.*, 2022). Therefore, we aim to contribute to this gap based on the organizational information-processing (OIP) theory (ATEŞ; VAN DEN ENDE; IANNIELLO, 2015; MOENAERT *et al.*, 2000; PREMKUMAR; RAMAMURTHY; SAUNDERS, 2005).

The OIP theory considers the organizational fit between *information-processing needs* and *information-process capability* to achieve higher organizational performance. The information-processing needs to consider understanding the business environment and the business relationships to reduce organizational uncertainties, while the information process capability comprises the information technology support for the organizational activities (PREMKUMAR; RAMAMURTHY; SAUNDERS, 2005). This capability has been recognized as a central role in dynamic capabilities (TEECE, 2018), such as organizational agility, the adaptation of manufacturing companies to their environments (CIAMPI *et al.*, 2022) in digital servitization contexts (TRONVOLL *et al.*, 2020). Thus, we adopt this perspective to the digital servitization business model configuration. Through this perspective, we consider that the fit between the required information processing needs and the information process capability will support the offer of Smart PSS solutions (FRANK *et al.*, 2019).

In the digital servitization perspective, the *information-processing needs* cover the necessary contextual information required to deal with environmental conditions and offer better solutions to the customer needs (FRANK *et al.*, 2022). Information-processing needs can be materialized in different types of contextual data and information required by the Smart PSS business model to provide digital solutions to the customers (OPRESNIK; TAISCH, 2015; PASCHOU *et al.*, 2020). The literature argues that external actors (e.g., suppliers, customers, and other business units) are important sources of information and data needed to run the digitalized solutions. This is because manufacturers cannot capture by themselves all the content necessary to offer integrative digital solutions for Smart PSS (OPRESNIK; TAISCH,

2015). Therefore, companies must focus on information-processing integration with the external actors at least on two levels: *raw data integration* and *data-driven service applications* (AGOSTINHO *et al.*, 2016; FIGAY *et al.*, 2012). As Andres, Poler, and Sanchis (2021) argued, *raw data integration* is one of the main concerns to foster collaboration in the service ecosystem and attend to information-processing needs. From this perspective, data exchange can face several challenges in the service ecosystem, including data interpretation, sharing this data across enterprise legacy systems and cloud environments, and the identification of the necessary data coming from different actors in the ecosystem. The second layer, *data-driven service applications*, involves several data-intensive cloud-based solutions that must be secure and reliable, requiring standards and interoperability conditions. Both layers operate based on data integration, although the first level is based on raw data and the second considers processed data. On both levels, concerns such as data sharing format, communication channels, privacy and security issues, and valuable data collection for the business application are present (PAN *et al.*, 2021). They are key aspects of increasing service demand in the growing technological trends while protecting social concerns that may become potential barriers for the Smart PSS solutions (KAHLE *et al.*, 2020). Companies that can integrate external data sources and information will be more able to attend to their information-processing needs to run their organizational activities (CIAMPI *et al.*, 2022), such as the Smart PSS business models, in our case.

On the other hand, *information-processing capability* considers the necessary technology infrastructure to fit with the information integration from the external environment (PREMKUMAR; RAMAMURTHY; SAUNDERS, 2005). In Smart PSS, data is generated from the virtualization of product and service-related assets and the usage of the Smart PSS. Data is collected and stored during the usage, usually through smart products or other digital technologies, for subsequent integration with other systems. Then, the servitized firms can analyze data and generate information about customer behavior, improving the existing offerings and creating new PSSs through service applications based on the identified customers' needs. In this sense, different digital technologies used for the delivery of Smart PSS can configure the information-processing capability since they will help integrate and provide the contextual data and information required. We adopt the information-processing capability to our multichannel perspective of digital service delivery in Smart PSS. The digital service delivery channels (Section 2.1) are equivalent to the information technologies

necessary for information-processing capability addressed by Premkumar, Ramamurthy, and Saunders (2005). The fit between information needs and information-processing capability is related to the cross-boundary communication capabilities of manufacturing companies (MOENAERT *et al.*, 2000). These channels comprise smart products, cloud-based systems, and virtually augmented systems, which will allow the organization to process and deliver real-time data and information from the ecosystem. The fit between these channels and the sources that support the information-processing needs should be articulated into different Smart PSS business models, as argued in the following hypotheses.

3.3 HYPOTHESES DEVELOPMENT

We use the OIP theory, as described in Section 2.2, to frame our hypotheses on multichannel digital service delivery and data integration with the actors of the service ecosystem, as represented in Figure 3.1. We focus first on the *multichannel digital service delivery* as a form of *information-processing capability*. We deployed it into three types of channels for service delivery (*smart products, cloud systems, and virtually augmented systems*), as previously described in Section 2.1 and which we hypothesize support three main different Smart PSS business models (Section 3.1). Then, we focus on the *information-processing needs*, which demand contextual data integration, as explained in Section 2.2. We focus on three main ecosystem actors that can provide real-time data integration to attend to information-processing needs (data integration with *other business units, suppliers, and customers*). The combination of information-processing needs (data integration with service ecosystem actors) with the information-processing capability (multichannel digital service delivery) should fit the organizational system requirements of the three different Smart PSS business models. Next, we describe these hypotheses.

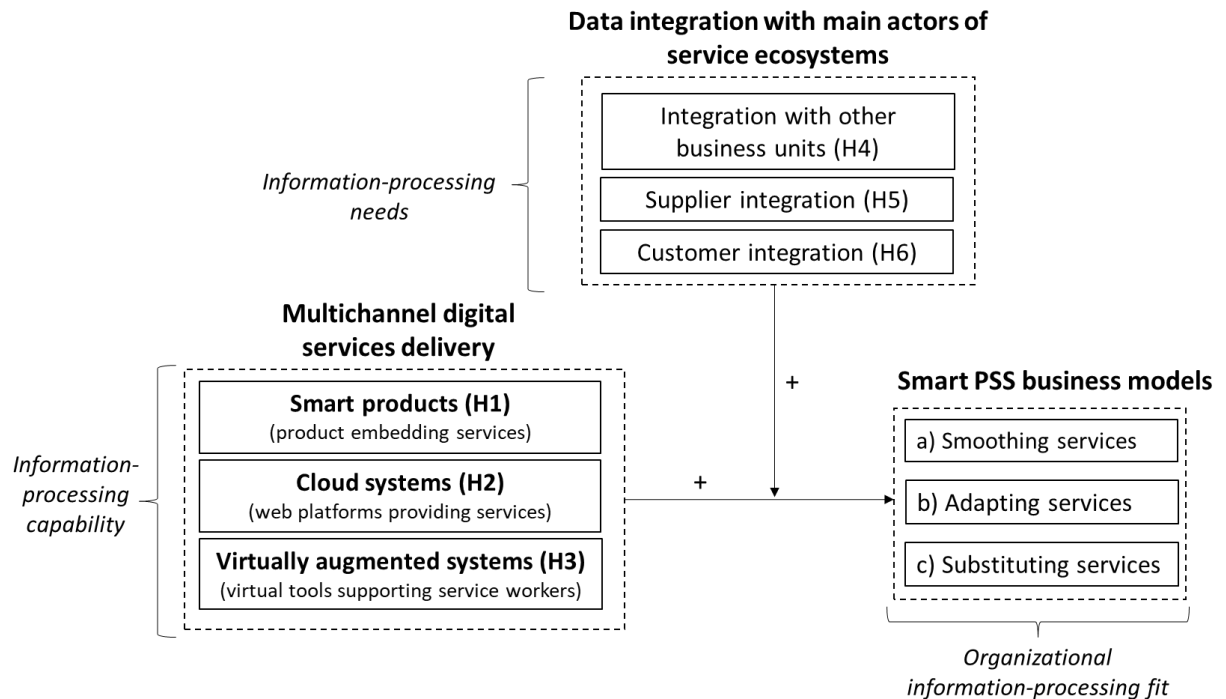


Figure 3.1 Conceptual research model

3.3.1 MULTICHANNEL SERVICE DELIVERY FOR SERVICITIZED BUSINESS MODELS

Several studies support the potential of service provision through digital channels in Smart PSSs (FRANK *et al.*, 2019; MARCON *et al.*, 2022; PAIOLA *et al.*, 2021). We argue that such channels provide the information-processing capability required for Smart PSS. Smart products generate product data, enable software-based customization services and allow for more advanced services with limited human intervention (PORTER; HEPPELMANN, 2014). Thus, *smart products* should play a key role in product-oriented services. They automate information-processing activities based on real-time data and delivery solutions for the customer (FRANK *et al.*, 2019; KAHLE *et al.*, 2020). Furthermore, *cloud systems* allow the manufacturing company to connect its solutions with other systems, extending the original functions and enabling more advanced digital services based on big data analysis and more value-added offerings to customers (OPRESNIK; TAISCH, 2015; PIROLA *et al.*, 2020). Through remote tools, cloud services support smoothing, adapting, and substituting services in product-oriented business models (FRANK *et al.*, 2019). *Virtually augmented systems, based on augmented and virtual reality*, also support digital services in PSS business models. Field services, like maintenance and inspections, are empowered by transmitting interactive information to field technicians (DALENOGARE *et al.*, 2019; MASOOD; EGGER, 2020). Virtual simulations support the redesign of products for new solutions and the virtual

commissioning of the product on the customer's process (GUO *et al.*, 2018). Previous studies such as Frank *et al.* (2019) and Kahle *et al.* (2020) have suggested that such technologies can become digital channels to deliver different services, supporting servitized business models. They can act as digital tools to process data sources and incorporate them into a wide set of Smart PSS solutions. However, the literature has not shown to what extent these different technology channels can help each of the main Smart PSS business models. Thus, we develop the following hypotheses:

***H1:** The provision of digital services through smart products is positively associated with the development of different types of Smart PSS business models, namely smoothing services (H1a), adapting services (H1b), and substituting services (H1c).*

***H2:** The provision of digital services through cloud systems is positively associated with the development of different types of Smart PSS business models, namely smoothing services (H2a), adapting services (H2b), and substituting services (H2c).*

***H3:** The provision of digital services through virtually augmented systems is positively associated with the development of different types of Smart PSS business models, namely smoothing services (H3a), adapting services (H3b), and substituting services (H3c).*

3.3.2 SERVICE ECOSYSTEM DATA-INTEGRATION BASED ON MULTICHANNEL DELIVERY SYSTEMS

The existent research on organizational changes in digital servitization highlights the need for integration of the ecosystem (KOHTAMÄKI *et al.*, 2019), in which other ecosystem actors are connected (SKLYAR *et al.*, 2019) and share cross-boundary data through ICT (OPRESNIK; ZANETTI; TAISCH, 2013). Although the ecosystem actors can involve many stakeholders, including government, universities, and many types of private sector representatives (KAHLE *et al.*, 2020), we focus our study only on those representing the core of the data integration to address the information-processing needs. Thus, we follow Benitez *et al.* (2021), who showed that suppliers and customers are the main actors in such integration. Moreover, Ayala *et al.* (2017) showed that other business units of large companies could act as quasi-independent actors that support the information-processing needs, making them another core actor of the ecosystem.

The integration of other business units of the same organization can be required to develop the service knowledge for the servitization process (AYALA *et al.*, 2017; MARTINEZ *et al.*, 2010). Cenamor, Rönnerberg Sjödin, and Parida (2017) argue that digital integration of the business units is essential for providing more advanced service offerings. Smart products, cloud systems, and virtually augmented systems demand strong integration between hardware and software-related capabilities in the whole life cycle of the solution (DOS SANTOS *et al.*, 2021; FRANK *et al.*, 2019). Therefore, different business units might be involved in the service provision of Smart PSS. These units are comprehended both in the back-end operations (the orchestrators) and in the front-end operations, which build the offerings for regional customers (CENAMOR; RÖNNBERG SJÖDIN; PARIDA, 2017). As shown by Ayala *et al.* (2017), such business units can operate as data and information providers for the servitization activity of the main company, being a kind of outsourcing of some information requirements of the company. Thus:

***H4:** Real-time data integration with other business units positively moderates the association of the three service channels, smart products (H4a), cloud systems (H4b), and virtually augmented systems (H4c), with the provision of different types of Smart PSS business models.*

Supplier data integration also supports the information-processing needs of Smart PSSs. Prior research argues that servitized supply chains must be more responsive to customer needs, requiring real-time information throughout the ecosystem and closer collaboration between partners (MOTA; SANTOS, 2021; SHAH *et al.*, 2020). Integration with different suppliers is important to create a valuable pool of resources and capabilities required to create more valuable offerings beyond the competencies of the manufacturing company (MARCON *et al.*, 2022). Real-time integration provides easy access to build these offerings with more agility (ELORANTA; TURUNEN, 2016; MARTINEZ *et al.*, 2010; OPRESNIK; TAISCH, 2015). For example, Hertz, the car rental company, collects and uses travelers' online booking data from airline companies such as KLM to show them available cars at the pre-identified destination (DELOITTE, 2014). The shoe manufacturer Nike, in turn, exchanges data with Apple, the digital technology supplier. Their partnership enables the creation of a digital platform for Nike's customers. Their continuous integration supports cloud services with additional information for the customers, increasing the customers' value perception of both

companies' offerings (BELAL; SHIRAHADA; KOSAKA, 2013). Considering this, we propose the following hypothesis:

***H5:** Real-time data integration with suppliers positively moderates the association of the three service channels, of smart products (H5a), cloud systems (H5b), and virtually augmented systems (H5c), with the provision of different types of Smart PSS business models.*

Lastly, data integration with the customer also enhances the application of digital services in Smart PSSs, providing support to the information-processing needs of the company. Studies have found evidence of the importance of customer involvement in servitization, especially for more advanced services (CENAMOR; RÖNNBERG SJÖDIN; PARIDA, 2017; SHAH *et al.*, 2020). Real-time customer data integration provides knowledge to the manufacturing company about a product's status and usage, and customer's processes and behavior, supporting the creation of useful information about the customer's value creation processes (MAGLIO; LIM, 2016). Thus, customer data integration is essential to make the customer a co-creator of the solutions. This enables the manufacturing company to segment its customers, provide more customized services, better price its offerings, and extend value-added services more swiftly (PORTER; HEPPELMANN, 2014; SJÖDIN *et al.*, 2020). Thus, we propose the final hypothesis:

***H6:** Real-time data integration with customers positively moderates the association of the three service channels, of smart products (H4a), cloud systems (H4b), and virtually augmented systems (H4c), with the provision of different types of Smart PSS business models.*

3.4 RESEARCH METHOD

3.4.1 SAMPLING

We conducted a cross-sectional survey of manufacturing companies from the southern regional office of the Brazilian Machinery and Equipment Builders' Association (ABIMAQ-Sul). This association was chosen due to its engagement in promoting digitalization initiatives on a national level and because it represents one of the strongest manufacturing sectors in this country, with a high potential for developing digital services through digital technologies. The sample comprises 143 companies of ABIMAQ-Sul. The questionnaires were sent directly to

the Chief Executive Officers or Operations Directors of the companies, and two follow-ups were sent to each within two weeks of the last one. We obtained 92 valid answers and a response rate of 64.33%, achieved with the help of an institutional e-mail sent by the ABIMAQ-Sul office to its member companies, promoting our survey. The office also presented this research in industrial seminars. The final sample composition was represented by 41% of small (< 100 employees), 37% of medium (100-500 employees), and 22% of large (>500 employees) companies. These companies attend to a wide range of market sectors, in which agriculture (48%) and metal products (34%) are the two most representative. In addition, all companies in the sample provide services like maintenance, customization, and/or leasing to their customers.

3.4.2 MEASURES AND SURVEY INSTRUMENT

Our study used five groups of questions (see Appendix A) represented as (i) sample characterization; (ii) digital technologies; (iii) smart products and digital services; (iv) supply chain integration; and (v) PSS models. First, “sample characterization” guaranteed our control variables (firm size) for the models and demographic data. Second, for “digital technologies”, a set of 22 technologies¹ was defined based on the previous work by Dalenogare et al. (2018) and with a round of interviews with 15 scholars and seven practitioners from technology institutes in Southern Brazil. Third, for “smart products and digital services”, we used a set of 8 features and services related to the digitalization process. These items were retrieved from the literature (HERTERICH; UEBERNICKEL; BRENNER, 2016; LERCH; GOTSCH, 2015; PORTER; HEPPELMANN, 2014; RYMASZEWSKA; HELO; GUNASEKARAN, 2017). Fourth, for “manufacturing service ecosystem data integration”, we considered the level of real-time data integration that manufacturing companies have with other business units, customers, and suppliers. We chose these three actors as they were considered in other quantitative research about inter-firm collaboration in servitization (AYALA, Néstor F.; GERSTLBERGER; FRANK, 2018; SHAH et al., 2020). We used the traditional supply chain management literature to define these variables in our survey (GEBAUER; PAIOLA; SACCANI, 2013; PAWAR; BELTAGUI; RIEDEL, 2009; VARGO; LUSCH, 2011). Lastly, for “PSS business models”, we used PSS literature to define our dependent variables. We focused only on product-oriented services (VISNJIC; RINGOV; ARTS, 2019). For this type of services, Cusumano, Kahl, and Suarez (2015) propose a taxonomy of three main types of business models offered by manufacturing companies: smoothing, adapting, and substituting

¹ For more details, check Frank, Dalenogare and Ayala (2019).

services. A five-point Likert scale was used to capture each of these groups of questions. The four groups (ii to v) were measured as the implementation level varying from 1 – Very low implementation to 5 – Advanced implementation. Thus, the highest degree shows an advanced maturity level on these items. Additionally, although the digital technologies group was not present in our conceptual research model, we included this group of questions because we used them for endogeneity, common method variance, and robustness tests.

3.4.3 VARIABLE OPERATIONALIZATION, RELIABILITY, AND VALIDITY OF MEASURES

We used exploratory factor analysis (EFA) with varimax rotation to extract orthogonal components for smart product and digital service items to examine unidimensionality. This technique has been used in many practices, especially to find potential latent constructs for digitalization metrics in recent years (BENITEZ *et al.*, 2022; DALENOGARE *et al.*, 2018). Our study's primary interest was evaluating the features of each group of variables rather than the variables individually. Therefore, we ran one round with the eight smart products and digital services variables. We used three criteria to assess the adequacy of our data to the EFA technique: the Kaiser–Meyer–Olkin (KMO) test, Bartlett's sphericity test, and the anti-image matrix for Measures of Sampling Adequacy (MSA) (HAIR *et al.*, 2018). We reached a final set of variables with a good percentage of explanation for the constructs (communalities > 0.500). The KMO test result was 0.785 (the generally recommended threshold value is 0.5), and Bartlett's sphericity test showed significance levels lower than 1% ($p\text{-value} < 0.01$). In addition, the anti-image matrix showed a good fitting since all correlation values were above the threshold of 0.5, as suggested by Hair *et al.* (2018). Our optimized solution was initially obtained with two factors. However, since some factor loading values were inappropriately mixed with the two constructs (relative values for both constructs), we opted to run the final test blocked with three main constructs. For the three main constructs, we found an explanation of 77.63% of the variance, indicating that these factors account for most of the variables' variance, as shown in Table 3.1.

For convergent validity, we analyzed the AVE, Alpha, and CR values from the main constructs. For all constructs, there is the goodness of fit since the values were above the normally suggested (i.e., $AVE > 0.5$; α and $CR > 0.6$) (HAIR; HOWARD; NITZL, 2020). Moreover, we also verified discriminant validity by assessing the heterotrait-monotrait ratio of correlations (HTMT) criterion (HENSELER; RINGLE; SARSTEDT, 2015). Since all values were below

the score of 0.85, all pairs of latent variables are discriminant in our model. Therefore, our results suggest goodness of fit in the measured constructs. We proceeded with a single-item construct measure for the other variables (ecosystem data integration and Smart PSS business models). We tested the normality of the data by examining skewness and kurtosis values. Overall, the data are normally distributed since the values were between the thresholds of ± 2.58 ($\alpha = 0.01$) (HAIR *et al.*, 2018).

Table 3.1 Rotated factor-loading matrix from the EFA and CCA procedures

Smart products and digital services	Factor loadings			Communalities
	Smart Products [SP]	Cloud Systems [CS]	Virtually augmented systems [VA]	
Monitoring	<u>0.714</u>	0.450	0.040	0.713
Control	<u>0.753</u>	0.450	0.051	0.772
Optimization	<u>0.841</u>	0.041	0.302	0.800
Autonomy	<u>0.804</u>	0.084	0.296	0.741
Remote digital service	0.169	<u>0.871</u>	0.262	0.856
Digital monitoring service	0.213	<u>0.879</u>	0.209	0.862
AR and VR NPD	0.136	0.167	<u>0.888</u>	0.836
AR maintenance	0.322	0.313	<u>0.656</u>	0.632
% of variance explained (cumulative)	52.69%	66.53%	77.63%	
Cronbach's alpha (α)	0.859	0.883	0.650	
Composite reliability (CR)	0.904	0.944	0.850	
Average variance extracted (AVE)	0.702	0.895	0.740	

3.4.4 RESPONSE BIAS, COMMON METHOD VARIANCE AND ROBUSTNESS CHECK

As Podsakoff, MacKenzie, and Podsakoff (2012) suggested, we employed procedural and statistical remedies for potential response bias. For procedural remedies, first, we pre-tested the

questionnaire with key respondents (CEO and Operations Directors), as explained in the sampling section (3.4.1), to obtain a broader view of the influence of digitalization on services. We also randomized the order to answer the group of questions and the questions inside each group to prevent possible associations between the variables. For statistical remedies, we employed Harman's single-factor test with exploratory factor analysis to address common method bias (PODSAKOFF *et al.*, 2003). The test with all variables considered in the model resulted in a first factor that explains only 38% of the observed variance. In addition, we also performed the marker variable technique to check the common method variance issue. The marker variable technique requires adding a variable from the questionnaire that is expected to be theoretically unrelated to the substantive variables (LINDELL; WHITNEY, 2001). As a marker, we chose the variable "*existence of management methods for production (e.g., lean production)*" from another group of questions in our survey that were not utilized in this study. The regressed models' results remained stable with the addition of a marker variable, which means there was no significant change in the model. Hence, we concluded that response bias is not a serious concern in this data set.

We also performed a series of robustness checks to ensure that our results were stable. We explored how the results of our regressions analysis might vary using five distinct approaches: (i) removal of control variables; (ii) inclusion of a new construct; (iii) individual analysis from predictors; (iv) analysis of individual significant moderation effects; and (v) competing model. In the first approach (i), we removed all control variables to ensure that the predictors (SP, CS, and VA) are not artifacts of the control variables. We included a new construct named "Base technologies" for the second approach, composed of IoT, cloud computing, big data, and analytics technologies. The results showed a significant direct effect of base technologies constructs, confirming the link between digital products and services and PSS business models, supporting the main findings of this study. In the third stage, we assessed the individual relationship of our predictors with PSS business models, excluding all predictors but one, and overall, the results remained stable, especially for the [VA] construct, which showed high kurtosis. Fourth, for the significant moderation effects, we verified the inclusion of the interaction terms individually and evaluated if these changed the results for the interactions. Overall, the results remained stable. For competing model analysis, we changed PSS business models with [SP], [CS], and [VA] constructs, and we did not find any interaction effect, showing that our models are not overfitted. As a matter of concern, since our sample size is

small, we performed a bootstrapping approach with 5,000 interactions to verify if our results remain stable with a large sample size. Overall, our results remained stable, i.e., the main direct and moderation effects found in each model did not suffer any changes. We only had slight changes for smoothing where supplier and customer showed a positive relationship, reinforcing our hypotheses since it indicates their presence is relevant for Smoothing PSS.

3.4.5 DATA ANALYSIS

We used hierarchical OLS regression models to test our hypotheses in Stata® 15.0. To test the moderation effects of the three ecosystem integration metrics (business units, supplier, and customer) on the relationship between digital products and services (SP, CS, and VA) and the three PSS business models (smoothing, adapting, and substituting). Then, using standardized values (Z-score), we multiplied the moderator by each independent variable, creating a multiplicative score for the interaction effect. Our final model contains six independent variables, nine interaction effects, four dependent variables, and two control variables. We tested to confirm the assumptions of linearity and homoscedasticity for all independent and dependent variables. We analyzed collinearity by plotting the partial regressions for the independent variables, while homoscedasticity was visually examined in plots of standardized residuals against a predicted value. All these requirements were met in our dataset for regression analysis. Finally, we evaluated the multicollinearity issue for our independent variables, as suggested by (HAIR *et al.*, 2018). Our results indicate a low VIF (< 3.0) for all variables, far away from the maximum allowed threshold of 10 (HAIR *et al.*, 2018).

3.5 RESULTS

The final regression results with direct and moderating effects are reported in Table 3.2. Unstandardized coefficients are reported since all scales were standardized with Z-scores because they represent a standardized effect (GOLDSBY *et al.*, 2013). As shown in Table 3.2, all models are statistically significant, and their R^2 changes, indicating improvements when direct and moderating effects were added. We opted to omit Model 1 since it only shows the effects of our control variables. In the final models from our hierarchical procedure (Model 3) we had a percentage of variance explanation of 58.4% (Smoothing PSS – $F = 8.512$, $p < 0.01$), 47.7% (Adapting PSS – $F = 3.978$, $p < 0.01$), and 46.9% (Substituting PSS – $F = 5.728$, $p < 0.01$), respectively.

Table 3.2 Results of the regression analysis with moderating effects

Independent variables	Smoothing Smart PSS		Adapting Smart PSS		Substituting Smart PSS	
	Model 2	Model 3	Model 2	Model 3	Model 2	Model 3
Small (control)	-0.031	-0.028	-0.021	-0.155	-0.158	-0.347*
Large (control)	-0.037	0.118	0.214	0.210	-0.567**	-0.525**
SP	0.404***	0.424***	0.329**	0.332**	0.413***	0.413***
CS	0.263**	0.210**	0.222*	0.232*	0.111	0.119
VA	0.202*	0.200**	0.032	0.031	-0.183*	-0.153
Business units	-0.088	-0.085	0.025	-0.025	0.076	0.017
Supplier	0.152	-0.115	-0.088	-0.267	0.153	-0.126
Customer	0.011	0.158	0.291*	0.278*	0.139	0.136
SP x business units		0.327**		0.300*		0.050
SP x supplier		-0.023		0.004		0.248
SP x customer		0.057		0.077		0.074
CS x business units		-0.698***		-0.557***		-0.372**
CS x supplier		0.372**		0.048		-0.210
CS x customer		0.175		0.440*		0.589***
VA x business units		0.044		0.047		0.152
VA x supplier		0.210		0.049		0.215
VA x customer		-0.496***		-0.238		-0.436**
F-value	8.333***	8.512***	5.578***	3.978***	5.623***	5.728***
R ²	0.445	0.662	0.350	0.477	0.351	0.568
Adjusted R ²	0.392	0.584	0.287	0.357	0.289	0.469
R ² Change	0.398***	0.216***	0.282***	0.128**	0.323***	0.217***

Notes: n = 92 enterprises.

¹Unstandardized regression coefficients are reported; * p<0.1.; ** p<0.05; *** p<0.01

Regarding the hypotheses: first, H1 (direct effect of smart products) was supported for the three product-oriented PSSs (smoothing, adapting, and substituting) proposed by Cusumano, Kahl, and Suarez (2015), at least at a significance level of 0.05. Regarding hypothesis H2 (direct effect of cloud systems), we had support for smoothing ($\beta = 0.263$, $p = 0.024$), and adapting ($\beta = 0.222$, $p = 0.075$) models, while substituting was not statistically significant. Hypothesis H3 for smoothing services was also supported (direct effect of virtually augmented systems) ($\beta = 0.202$, $p = 0.088$). We also found a negative association for substituting in Model 2 ($\beta = -0.183$, $p = 0.098$), not supporting this hypothesis.

For the interaction effects (H4, H5, and H6) we had only partial support (not having positive interactions in all models) for our hypotheses. For smoothing services, we had support for H5 (supplier) for [CS] ($\beta = 0.372$, $p = 0.044$) and H4 (business units) for [SP] ($\beta = 0.327$, $p = 0.016$). In the case of adapting services, we had support for H6 (customer) for [CS] ($\beta = 0.440$, $p = 0.098$) and H4 (business units) for [SP] ($\beta = 0.300$, $p = 0.071$). Finally, for substituting services we only had support for H6 (customer) for [CS] ($\beta = 0.589$, $p = 0.006$).

We also submitted the regression models to statistical power analysis as a final complementary analysis. We first estimated the population effect size for R² using Cohen's f^2 estimation (COHEN; COHEN; STEPHEN, 2003). All the regression models showed high statistical power (VERMA; GOODALE, 1995) and 74 degrees of freedom. For the final model of smoothing, we obtained $f^2 = 1.96$, which represents a statistical power of ≈ 0.99 at $\alpha = 0.01$. Adapting resulted in $f^2 = 0.91$, representing a statistical power of ≈ 0.97 at $\alpha = 0.01$. The final model for substituting showed an $f^2 = 1.31$, that is, the statistical power of ≈ 0.99 at $\alpha = 0.01$. Furthermore, we also considered the statistical power of the partial coefficients using Cohen's f^2 estimation for the predictors and the range of effects, where below 0.15 is a small effect, between 0.15 and 0.35 a medium effect, and above 0.35 a large effect. From all significant effects in the four models, we obtained at least medium effects, suggesting that our results are in accordance with the minimum statistical power necessary for regression models (COHEN; COHEN; STEPHEN, 2003).

3.6 DISCUSSIONS

We divide our discussion into two subsections. Firstly, in Section 3.6.1., we discuss the general patterns of service provision through digital technologies found in our results (Table 3.2). Then, we look at the big picture in each business model (Section 3.6.2), analyzing the combination

of such technologies with data integration to understand how these business models work in Smart PSSs and contribute to the OIP theory.

3.6.1 GENERAL CHARACTERISTICS OF SERVICE PROVISION THROUGH DIGITAL TECHNOLOGIES

Our findings evidenced that the delivery of digital services through *smart products* is a central aspect of the three Smart PSS business models (Table 3.2). In this sense, we corroborated what prior studies have suggested on smart products for digital servitization (BEVERUNGEN *et al.*, 2019; KOHTAMÄKI *et al.*, 2019; VALENCIA *et al.*, 2015) but also expanded this view by showing that such digital provision is present in all business models investigated. Consequently, smart products act as a key digital delivery channel, providing the information-processing capability to the Smart PSS business models.

We found *cloud systems* an important form of digital service channel delivery. However, cloud systems as a digital channel for service delivery decrease when the manufacturer integrates data from other business units (i.e., negative moderation between cloud services and other business units). Our original hypothesis (H4b) expected a positive moderation suggesting that the manufacturer offers cloud services for the Smart PSS business models enriched with external data from other business units. Instead, our results suggest that when other business units are involved through data integration, cloud services are externalized into these business units. In such a case, these units will act as providers of the information-processing capability (external cloud services) and the information-processing need (i.e., the provision of the required data for the PSS business model). Therefore, while we expected that the information-processing fit would happen by means of the PSS business model offered, this case shows that this fit can also happen in an external actor that will provide the final digital output for the Smart PSS business model operation. This indicates a strategy of centralizing cloud services in other business units that are better prepared to develop the data-related skills required to address customer demands (SKLYAR *et al.*, 2019). In some cases, this is necessary for manufacturers that do not have all the information-processing capability, especially when customers' data integrity is demanded due to cybersecurity issues or sensitive information about the customers. As previously suggested in the propositions of the study conducted by Frank *et al.* (2019), this can become a barrier for Smart PSS, and the delegation of such responsibility to those actors who can provide the required confidence to the market can

become a central aspect of the Smart PSS business model. Other business units can own information-processing capability to deal with the main concerns of these technological trends, such as social demands for data protection (BRESCIANI *et al.*, 2021; OPRESNIK; TAISCH, 2015), cybersecurity threats (PASCHOU *et al.*, 2020), or digital surveillance problems (GRUBIC; PEPPARD, 2016). Customers can feel more confident when specialized companies in the ecosystem take care of such aspects.

However, since the internal provision of cloud systems is also positively moderated by real-time data integration from other actors depending on each Smart PSS business model (Table 3.2), we assume that there might be two levels or types of cloud systems, namely: a *customer-oriented cloud service*, based on provision through other business units that will centralize customer-oriented web services; and another type of provision which we called *cloud services for product-oriented solutions*, which are related to smart product operation (BABICEANU; SEKER, 2020; PORTER; HEPPELMANN, 2014). The first is meant for data integration with customers for adapting and substituting, and the latter is for data integration with suppliers for smoothing services. Customer-oriented cloud services operate as a front-end information-processing capability, and cloud services for product-oriented solutions will operate as an internal information-processing capability for the back-end information-processing needs. This view is supported by the twofold data-integration role described by Frank *et al.* (2019) for Smart PSS when a company adds value to both the external customer and the internal processes through cloud services data-integration.

Regarding virtually augmented systems (VA), we observed direct positive effects only for smoothing service provision, which is expected due to the nature of these services, as maintenance activities or installation. As they involve the intensive participation of service workers, they can be supported by this kind of digital solution to address the information-processing needs when the service is executed (MASOOD; EGGER, 2020). Surprisingly, we did not find any association of VA with *adapting* services, which can be due to the early stages of such types of virtual tools that are still evolving and not presenting the full potential expected by them, as shown by Dalenogare *et al.* (2019) and Dornelles, Ayala and Frank (2022). The application of virtual tools for product development is less popular than for maintenance inspections (MUÑOZ-SAAVEDRA; MIRÓ-AMARANTE; DOMÍNGUEZ-MORALES, 2020; PENTENRIEDER; MEIER, 2008). We assume that workers might not be ready for those applications considered in our study. In addition, the lack of association of VA with adapting

service suggests that, in this case, the customized solutions are offered through the smart product itself, and its combination with cloud systems since these other two digital channels present statistical association with this business model (Table 3.2). This result is supported by Frank *et al.* (2019), who show that adapting services enabled by digital technologies tend to focus on data customization for products rather than engineering-based activities, as usually happens in manual adapting services. On the other hand, we only found a negative moderation of the customer with VA for substituting services, which was also observed in the smoothing services for such moderation. This should be interpreted in the general picture of each business model, as discussed in the next subsection.

3.6.2 A MULTICHANNEL DIGITAL SERVICE DELIVERY AND ECOSYSTEM PERSPECTIVE ON SMART PSS BUSINESS MODELS

Figure 3.2 summarizes the relationships found and our interpretations for smoothing Smart PSS based on the results in Table 3.2. In smoothing services, the manufacturer delivers services through the three digital channels (positive direct effects). However, the results show that when the manufacturer has real-time data integration with other business units, smart product provision is enhanced (positive moderation), while cloud systems are less commonly used in manufacturer provision (negative moderation). As represented in Figure 3.2, other business units tend to centralize the customer-oriented cloud service solutions (negative moderation according to Table 3.2), while this external unit provides data for the smart product operation (positive moderation according to Table 3.2). In other words, this unit operates as the data-integration bridge between the front-end service provision and the connected smart product because it operates as a negative and positive moderator for two different service delivery channels in the same business model (Table 3.2). From an OIP perspective, this means that the fit between information-processing needs and capability happens inside this third party who provides the solution for the business model. One example of this business model is General Motor's OnStar service, a smoothing service that enhances the value of vehicles through the provision of digital solutions (CUSUMANO; KAHL; SUAREZ, 2015). General Motors developed a dedicated business unit for its OnStar cloud service, which provides front-end solutions to the customer (SLYWOTZKY; WISE, 2003). As the OnStar service is executed, this business unit provides processed data to General Motors' manufacturing division, which uses it to monitor product performance, improve product characteristics and provide additional services (FRANK *et al.*, 2019). Therefore, other business units can become a source of

organizational information-processing without internalizing it into the company's own structure as in other business models (PORTER; HEPPELMANN, 2015; SKLYAR *et al.*, 2019). In this sense, the organizational information-processing fit between the information-processing needs (data to run the smoothing service business model) and the information-processing capability (digital technologies and knowledge for the operation) can be outsourced to a third party. This is more important in smoothing services, where the company is mainly focused on the product offering as its core business (CUSUMANO; KAHL; SUAREZ, 2015).

Moreover, our results showed that cloud services are more developed when the manufacturer integrates real-time data integration with suppliers (positive moderation, Table 3.2). Our graphical framework (Figure 3.2) represents an integration through what we call product-oriented cloud service solutions. From the OIP perspective, the information-processing needs and capability are reinforced by the data integration between suppliers and the cloud services used as a digital channel for service delivery. For instance, besides the apps and solutions for the customer, the manufacturer may have embedded sensors in the car engine. This can integrate raw data with the engine provider (or any other subsystem of the product), allowing for detecting anomalies in product operation (BABICEANU; SEKER, 2020; PAGOROPOULOS; MAIER; MCALOONE, 2017). An example cited in the literature is Canon, which integrated an independent dealer network into its cloud services to extend its maintenance provision (ARDOLINO *et al.*, 2017). Such cloud services are more technical and focused on smart product operation (FRANK *et al.*, 2019). Lastly, the greater the data integration with the customer, the less the company focuses on virtually augmented services (negative moderation, Table 3.2). Customer data integration is materialized by remote activities with the customer through cloud systems, while AR/VR tools focus on supporting the manual execution of services in contact with the customer, as in the case of elevator maintenance (DALENOGARE *et al.*, 2019). This explains the opposite effect in smoothing services, which leads to a trade-off.

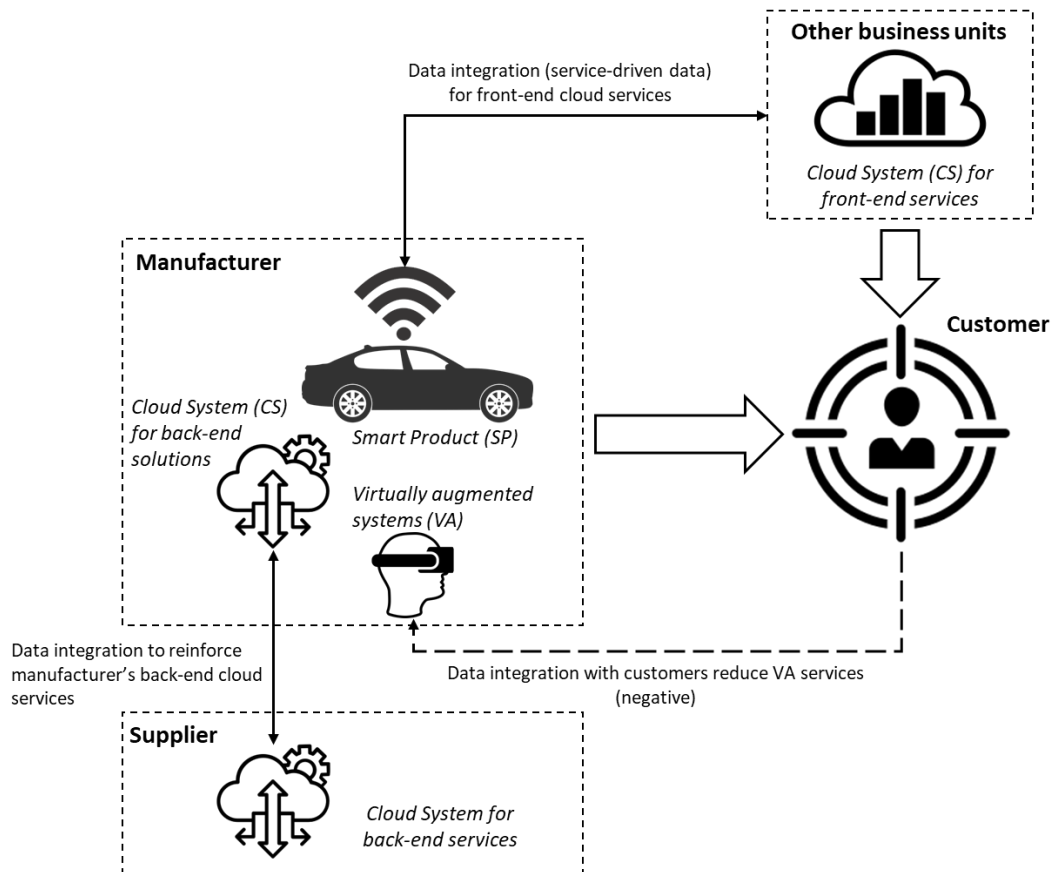


Figure 3.2 Graphical framework representing provision in the Smoothing Smart PSS business model

In the case of adapting Smart PSS business models (Figure 3.3), the service solution tends to operate more simply than in smoothing, as shown in our results in Table 3.2. Firstly, other business units again offer cloud service providers for customer-oriented solutions (negative moderation). This supports data integration with the smart product offered by the manufacturer (positive moderation). Thus, information-processing fit can happen through the external business unit that provides the cloud service, as discussed before. On the other hand, this model shows that the manufacturer can also provide more cloud-based services if it works with data integration with the customer (positive moderation), providing its own information-processing capability to the Smart PSS business model. This model shows that there are two aspects to be explored in adapting services, online services related to solutions obtained from the customer's operation (customer-oriented solutions) and hardware-related services oriented to the customer's use of the smart product (product-oriented service solutions). For instance, Ayala *et al.* (2017) presented the case of a German dental scanner manufacturer that adapted its solution and business model to enter a new market. The company developed a business unit to provide online solutions for customers so they could better use and optimize the product applications. On the other hand, the company could provide predictive maintenance based on an analysis of

product usage data collected using sensors and cloud solutions. Similarly, Siemens provides smart products for industrial processes complemented by MindSphere, its cloud platform for digital services, managed by a dedicated business unit of the company (COLLIS; JUNKER, 2021). The same happens in ABB robots, as they offer cloud services for optimization (other business units) and hardware support based on product-oriented cloud services for technical aspects of the connected robot (PORTER; HEPPELMANN, 2014; SERVICES, 2020).

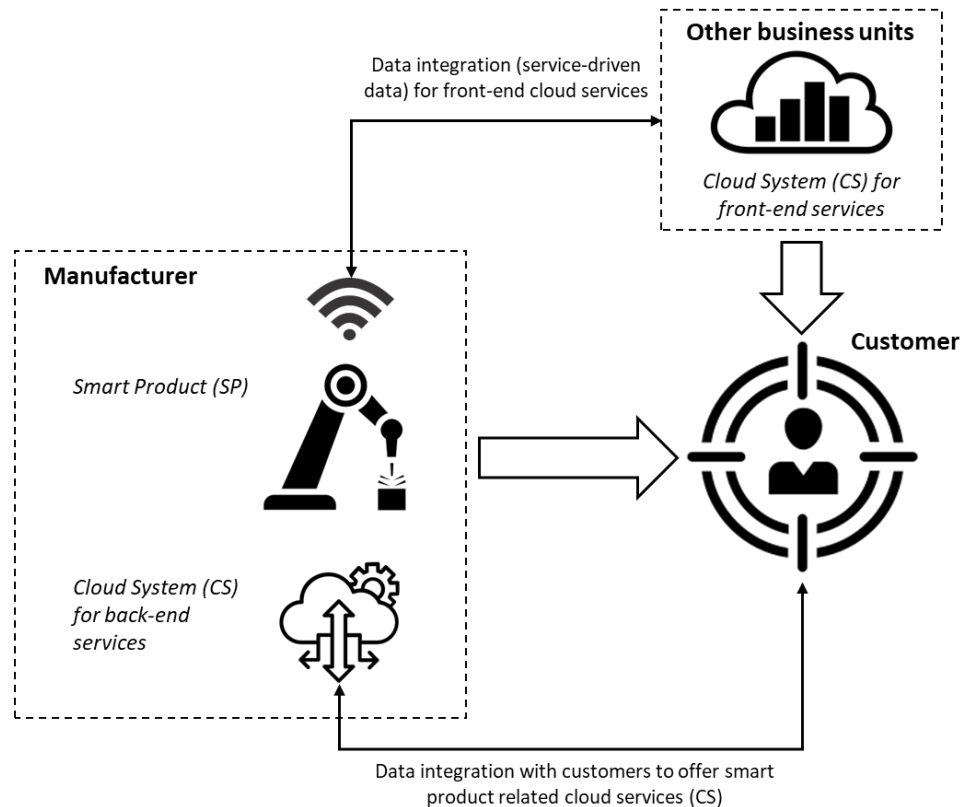


Figure 3.3 Graphical framework representing provision in the Adapting Smart PSS business model

For substituting services, Figure 4 summarizes the findings in Table 3.2. Also, in this case, cloud services are provided by other business units when data is integrated from those units with the manufacturer, and the smart product is directly associated with this business model being developed by the manufacturer. However, unlike the other two, in this case, we did not find evidence of smart products being supported by data integration with an external business unit. This suggests that – differently from the other two types of service provision, the customer-oriented service, and the smart product were interdependent – in this case, they stand alone. From an OIP perspective, there is a twofold information-processing capability to address the data requirements of the business model. The Car2Go car-sharing business model is an example (FRANK *et al.*, 2019). The customer uses an external app to manage car selection,

reservation, and control, while the car is connected for localization monitoring and energy control. Thus, in this business model, the company is mainly dedicated to providing the service, with fewer connections with other business units, even though these can use data collected from data-driven service applications to improve the manufacturing of smart products, as is the case with Daimler and Car2go. Similarly, other pay-per-use solutions follow this model, such as mobility as a service solutions with electric scooters and bikes (ARDOLINO *et al.*, 2017; WONG; HENSHER, 2021). In such cases, the manufacturing company is not connected in real-time with the smart product but uses collected data for repairs and inspections. Thus, both cloud systems and smart products are complementary parts of an end solution (SUAZO, 2021). On the other hand, real-time data integration with the customer plays a more important role in this model to enhance the manufacturer's cloud-service-based technologies (SHAH *et al.*, 2020). This is because cloud systems were only significant when moderated by the customers and not directly, as in the previous business models. In the case of Car2Go, while the customer is using a car, the manufacturer can receive raw data on certain vehicle parameters to improve the smart car solution. It can also detect car problems such as low performance or breakdowns that prompt maintenance provision (FRANK *et al.*, 2019). At the same time, data integration with customers competes with virtually augmented systems. In this case, an alternative to customer data integration might be using service workers that periodically inspect the product for failures, like in the referred model of elevator maintenance service and in Hyundai, which launched an AR owner's manual that helps customers to perform repairs on the cars by themselves (BUSINESS, 2020).

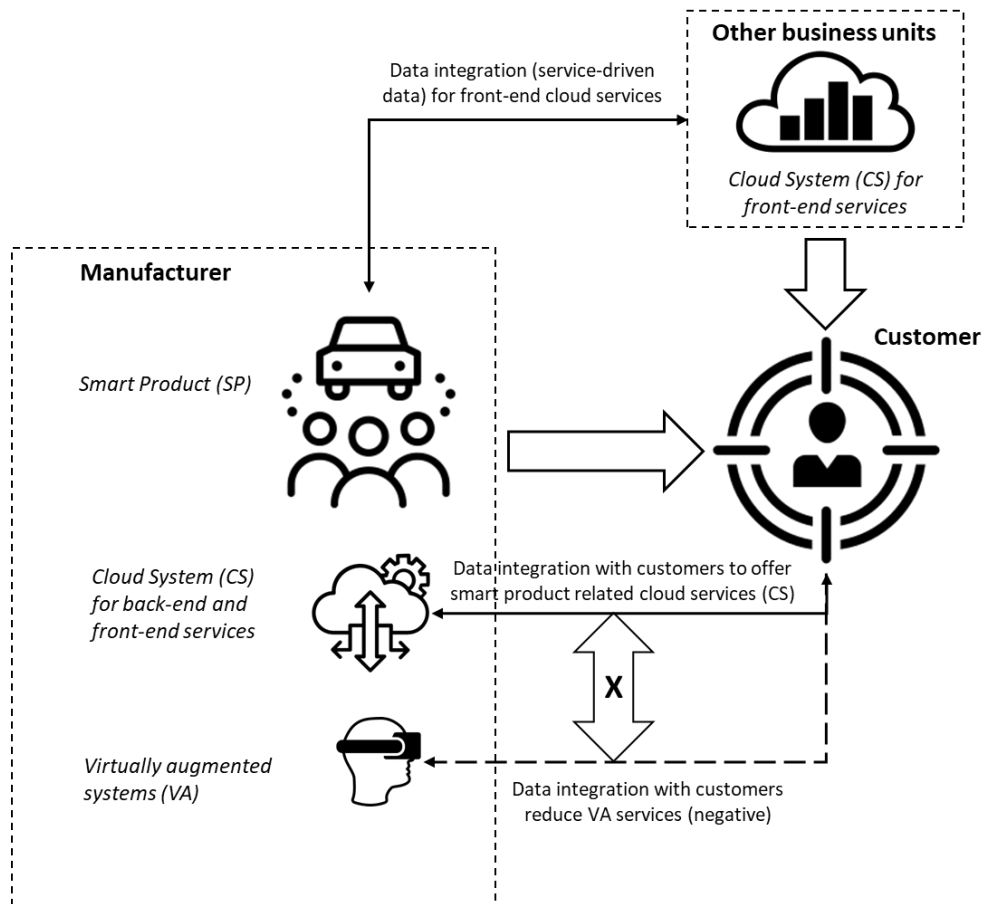


Figure 3.4 Graphical framework representing provision in the Substituting Smart PSS business model

3.7 CONCLUSIONS

This article considers Smart PSSs from a multichannel digital services delivery system. We addressed three main digital service channels: services embedded in products (smart products), services provided through digital platforms (cloud systems), and services offered by workers supported by AR/VR tools (virtually augmented systems). We analyzed the influence of the PSS ecosystem by adopting an OIP perspective. Using this perspective, we argue that the ecosystem's actors can help fit the information-processing needs and capability, supporting the manufacturer with data and information to better structure the Smart PSS business models.

The results show that at least for smoothing and substituting Smart PSS business models, different digital channels can provide product-oriented services combined with data integration from different actors. VA can be an alternative to provide improved services to customers who are unwilling to share their data. However, despite the unique features of virtual tools, our results confirm the growing trend of real-time connectivity with multiple actors through smart products and cloud systems within Smart PSSs, firstly predicted by the Internet of Things

concept, and now with the advent of big data applications. In this context, the literature already recognizes a change of organizational culture centered on data applications. Our results provide statistical evidence for advancements to clarify Smart PSSs and their complexity within service ecosystems. These results bring theoretical and practical contributions, as follows.

3.7.1 THEORETICAL CONTRIBUTIONS

By adopting an OIP perspective, we clarify how databased systems integrate products and services within Smart PSSs and the interconnectivity of the networked actors that add value to the solution, including the customer. Our findings show how digital technologies increase the value of both products and services of servitized solutions. Several studies acknowledged digital technologies as key resources for the servitization process, in which some studies complement this view with data integration with external actors (SHAH *et al.*, 2020; SKLYAR *et al.*, 2019). Our findings bring advancements in this direction. Firstly, we show how digital technologies support the PSS business models proposed by Cusumano, Kahl, and Suarez (2015) and Frank *et al.* (2019). Our study brings confirmatory results of this trend, a gap in digital servitization literature (PASCHOU *et al.*, 2020). However, we advance a step further by focusing not on the relationship of the ecosystem but on the data integration aspects, which was previously acknowledged by Kahle *et al.* (2020) as a need for further research in this field. In this sense, we extended the findings of Opresnik and Taisch (2015), which suggest data exploitation as the next step of servitization to bring a competitive advantage to manufacturers. We showed how Smart PSS uses data to enable and improve business models with external actors. In this context, we also complemented Shah *et al.* (2020) by specifying supplier integration for basic services provision (smoothing services) through cloud services for product-oriented solutions and the customer integration for advanced services (adapting and substituting services) through a customer-oriented cloud service. Lastly, we also complemented Sklyar *et al.* (2019), showing the decentralization of digital services (centralization in other business units) for Smart PSSs. Thus, our study provides advancements to clarify this gap, being one of the first to provide empirical evidence of the role of data integration from service ecosystems in the different forms of configuring digital channels to provide alternative servitized business models. These findings are important to understanding the technical aspect of Smart PSSs, organizational changes, and the relationship between these key aspects of the digital servitization process.

In addition, we adopted the OIP theory, which is a growing theory in the research of digital transformation and ecosystems. By adopting this theory, we show different forms of data sources that Smart PSS business models will use to fit the information-processing needs for the delivery of digital services. We also show the information-processing capability required for the digital capabilities for such delivery. This contribution expands the digital servitization literature since it brings an information system perspective for Smart PSS business models, which is necessary to operationalize such business models. Focusing on this perspective can also help to understand the operational perspective of the technological changes in the digital servitization field, as more data is integrated and new business opportunities emerge from this.

3.7.2 PRACTICAL CONTRIBUTIONS

Regarding the practical contribution, our results show the extent of centralization and integration strategies according to the different servitized business models (FRANK *et al.*, 2019) and which type of actors should be integrated (MARCON *et al.*, 2022). We approached these strategies through data integration, an important perspective of the digital servitization process (KAHLE *et al.*, 2020). Our findings support manufacturers in decision-making regarding systems integration with external partners, considering their strategic objectives. As creating an efficient and real-time integration of the ecosystem demands significant investments and efforts from the engaging parties, our results bring important advances to clarify the complexity of the digital servitization process. Practitioners can learn how to configure their ecosystem arrangements based on these results, which continue prior contributions from Kahle *et al.* (2020) on the role of digital transformation in ecosystem building. Practitioners can start by selecting the desired Smart PSS business model to implement in their companies, and based on this. They can consider how each technology can help create service digital channels that need the support of external data integration from other actors. In this sense, our study helps practitioners develop a strategy of digital servitization implementation since they can use these configurations to plan how to address issues like the data integration with each actor, the technology development for service delivery, and the offering of the Smart PSS business model.

3.7.3 LIMITATIONS AND FUTURE RESEARCH

Our study has some limitations by using a sample of manufacturers within one industrial sector. We could confirm and clarify some existing findings of organizational changes in the digital

servitization process. However, as our sample mostly consists of hardware-oriented companies, our results have limitations for companies of other industrial sectors keener to develop a software-oriented business model. Thus, other industrial sectors can be considered in future research for a broad understanding of the role of digital technologies in service provision and data integration in servitized business models. As our study focuses on analyzing general patterns in a set of manufacturers, future research may develop case studies to analyze how these solutions are built depending on each actor's characteristics. In addition, we only focused our study on the main required actors contributing to data integration for Smart PSSs, according to the literature. Another research opportunity is to study customer experience and loyalty for customized solutions when a Smart PSS is provided in an ecosystem approach (FRANK *et al.*, 2022). This is important because customers may have data security concerns arising from the various means of data integration, which may hinder the operationalization of business models such as those explored in this paper.

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APPENDIX A – QUESTIONNAIRE

Questionnaire item to assess control variables: Indicate the approximated number of employees in the company.

Questionnaire items to assess Smart Products (SP) (adapted from Porter and Heppelmann, 2014). *Implementation Likert scale: 1 – “Very low implementation” to 5 – “Advanced implementation”*. *Cronbach = 0.859. Factor loadings are shown in parentheses.*

Indicate the degree of development of machines/equipment with connectivity for:

- a. Equipment monitoring (0.714)
- b. Equipment control via software (0.753)
- c. Equipment optimization via predictive analysis of product usage (0.841)
- d. Equipment autonomy with self-coordination functions (0.804)

Questionnaire items to assess Cloud systems (CS) (adapted from Lerch and Gotsch, 2015; Herterich, Uebernickel and Brenner, 2016; Rymaszewska, Helo and Gunasekaran, 2017). *Implementation Likert scale: 1 – “Very low implementation” to 5 – “Advanced implementation”*. *Cronbach = 0.883. Factor loadings are shown in parentheses.*

Indicate the degree of service digitalization:

- a. Remote digital services (e.g., app support, digital platforms, etc.) (0.871)
- b. Client`s equipment digital monitoring services (0.879)

Questionnaire items to assess Virtually augmented systems (VA) (adapted from Frank, Dalenogare and Ayala, 2019; Meindl *et al.*, 2021). *Implementation Likert scale: 1 – “Very low implementation” to 5 – “Advanced implementation”*. *Cronbach = 0.650. Factor loadings are shown in parentheses.*

Indicate the degree of development of Smart working:

- a. Augmented reality for maintenance services (0.656)
- b. Augmented/virtual reality for new product development (0.888)

Questionnaire items to assess Data integration with the main actors of service ecosystems (SVC) (adapted from Pawar, Beltagui and Riedel, 2009; Vargo and Lusch, 2011; Paiola *et al.*, 2013; Ayala, Gerstlberger and Frank, 2018; Frank *et al.*, 2019). *Implementation Likert scale: 1 – “Very low implementation” to 5 – “Advanced implementation”.*

Indicate the degree of development of the following technologies and/or concepts:

- a. Real-time digital integration with other business units
- b. Real-time digital integration with suppliers (upstream)
- c. Real-time digital integration with customers and distributors (downstream)

Questionnaire items to assess PSS Business models (adapted from Visnjic, Ringov and Arts, 2019; Cusumano, Kahl and Suarez, 2015). *Implementation Likert scale: 1 – “Very low implementation” to 5 – “Advanced implementation”.*

Indicate the degree of service offerings to the clients which:

- a. Aims to improve the performance of the product (Smoothing Smart PSS)
- a. Aims to extend product functions (Adapting Smart PSS)
- b. Aims to substitute the product sale (Substituting Smart PSS)

4 ARTICLE 3 - INTER-FIRM COLLABORATION FOR DIGITAL SERVITIZATION: A SOCIAL EXCHANGE THEORY PERSPECTIVE

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Abstract:

The servitization literature has evidenced that the development and provision of digital solutions usually happen through collaborative ecosystems, but little is known about the different arrangements that ecosystem's actors can follow to provide digital solutions. We propose four configurations of inter-firm collaboration, based on the level of joint value creation activities and value capture interdependence among the actors: expanded business, enhanced business, platform business and symbiotic business. We analyze how these different collaboration types operate based on a multi-case study approach using the Social Exchange Theory (SET) to examine actors' interactions. We focus on four elements of SET: trust, commitment, reciprocity, and power. We found that trust, commitment and reciprocity are related to value creation and capture dynamics, while power is mostly affected by other external factors. These four elements allow to define the operationalization of the four types of inter-firm collaboration in digital servitization ecosystem. We contribute to the theory showing how service and digital suppliers interact with the servitized product firm in the ecosystem. Managers can learn the elements involved in different business models and collaboration arrangements for the provision of servitized digital solutions aiming to better decide the servitization strategy they want to follow.

Keywords: Digital Servitization; Collaboration; Ecosystems; Smart Product-Service Systems; service partners.

4.1 INTRODUCTION

Digital servitization is considered a transformation process to include digital service solutions as part of a product firm's business model (FRANK *et al.*, 2019; KOHTAMÄKI *et al.*, 2019). This transformation results from the convergence of two concepts: servitization and digitalization (FRANK *et al.*, 2019; VALENCIA *et al.*, 2015). While servitization focus on innovating the business model through the development of new services to create new value for customers and obtain new revenue sources (BAINES *et al.*, 2017; FRANK *et al.*, 2022), digitalization, on the other hand, focuses on the application of digital technologies such as the Internet of Things (IoT), cloud computing, big data analytics and artificial intelligence to leverage the companies' activities (ARDOLINO *et al.*, 2017; PORTER; HEPPELMANN, 2014). The use of digital technologies in servitization drives new ways to innovate the value offered by product firms in solutions composed of products and integrated services (KOHTAMÄKI *et al.*, 2019). For instance, through embedded sensors and cloud computing, products can be monitored to provide data about product usage which is required for service processing (PORTER; HEPPELMANN, 2014).

As Kohtamäki *et al.* (2019) have warned, the process of digital servitization demands mastering product and service capabilities combined with other capabilities related to the digital technologies. In this sense, product firms may find hard to manage so many different sets of capabilities (BENITEZ *et al.*, 2021; KAHLE *et al.*, 2020). Therefore, the role of collaboration with different actors of the ecosystem becomes relevant to acquire and combine such capabilities (FREIJE; DE LA CALLE; UGARTE, 2021; GEBAUER; PAIOLA; SACCANI, 2013). The digital servitization literature has reported several case studies with product firms joining forces with service providers and digital technology suppliers (Ardolino *et al.*, 2017; Eloranta and Turunen, 2016; Freije *et al.*, 2021; Sklyar *et al.*, 2019). However, despite the recognized importance of inter-firm collaboration in servitization, the literature still lacks empirical evidences about this topic (KAMALALDIN *et al.*, 2020; SHAH *et al.*, 2020). When the literature addresses the role of collaboration, the interaction between the servitized firms and their ecosystems are treated in a generic manner without discriminating the potential different arrangements that companies can implement with their partners to provide digital solutions. The more advanced the digital solutions, the more collaboration would be required with suppliers in different technological capability domains, such as sensors, connectivity infrastructure, and digital services, creating different types of collaboration types (BENITEZ;

AYALA; FRANK, 2020; MAZHELIS; LUOMA; WARMA, 2012). Thus, although not yet well explored, studies suggest that different collaborative configurations can be designed for digital servitization. In this context, the following research question emerges: *How can inter-firm collaboration be configured for digital servitization?*

To answer this question, we first propose a theoretical framework for inter-firm collaboration digital servitization, taking into account two dimensions: value creation joint activities and value capture interdependence (DYER; SINGH; HESTERLY, 2018). Based on this framework, we propose four main collaborative configurations: (i) *expanded business*, i.e., an independent collaboration that generates additional benefits; (ii) *enhanced business*, i.e., collaboration with joint activities oriented to the digital servitization of a focal firm; (iii) *platform business*, i.e., an inter-firm combination of products and services with lower relationships among the actors but higher value capture interdependence; and (iv) *symbiotic business*, i.e., collaboration for integrative co-business. Then, through a multiple-case study approach, we analyze the characteristics of these configurations. We use the Social Exchange Theory (SET) to investigate how the ecosystem actors interact in each of these inter-firm collaboration patterns following the base of the SET elements: trust, commitment, reciprocity, and power. This research contributes by defining the main configuration patterns of collaboration to leverage digital servitization, providing details of how these patterns are operationalized through social exchange between actors. We also provide guidance for practitioners to advance in digital servitization. We show alternatives for collaboration with service providers and digital technology suppliers and provide details of what managers can expect from each type of relationship.

This paper is structured in six sections. After this introductory section, we provide a theoretical background about inter-firm collaboration in digital servitization and SET. In the third section, we describe our analytical method and in the fourth we set out our results. We discuss our findings in the fifth section, followed by the conclusions of our research in section 4.6.

4.2 THEORETICAL BACKGROUND

4.2.1 INTER-FIRM COLLABORATION FOR DIGITAL SERVITIZATION

Digital servitization has been acknowledged as a way to *create* and *capture value* through innovative business models (GARCIA MARTIN; SCHROEDER; ZIAEE BIGDELI, 2019;

KOHTAMÄKI *et al.*, 2019). *Value creation* refers to the processes and activities required to generate and deliver the value offered by a company to its customers, while *value capture* is defined as the way in which a company appropriates the value created for its business, as either financial or non-financial returns (CHESBROUGH, 2002; CHESBROUGH; LETTL; RITTER, 2018). By offering solutions with products and digital services, product firms can gain more revenue from their customers, increase customer loyalty and obtain better market access (GARCIA MARTIN; SCHROEDER; ZIAEE BIGDELI, 2019; VALENCIA *et al.*, 2015). However, in order to develop and benefit from digital servitization, product firms need to develop capabilities in three domains: products, services and digital technologies (COREYNEN; MATTHYSSENS; VAN BOCKHAVEN, 2016; HUIKKOLA *et al.*, 2021), which can become too costly for them (BENEDETTINI; SWINK; NEELY, 2016). Instead, through collaboration, product firms can combine synergic capabilities from different partners, such as service providers and digital technology suppliers, to co-create value and obtain competitive advantage, but without the need to master every knowledge domain (KAHLE *et al.*, 2020; BENITEZ *et al.*, 2021). By means of collaboration, networked companies can co-create and capture value and thereby obtain a possible joint competitive advantage for the whole network (DYER; SINGH, 1998). According to Dyer, Singh, and Hesterly (2018), complementary resources among network partners offer the potential for value creation in collaborative arrangements. More value can be created by means of joint activities, determined by relation-specific assets and knowledge-sharing routines. Governance is then used as a safeguarding mechanism to address the risk of opportunistic behavior by the partners (DYER; SINGH, 1998).

The understanding of *value creation* and *value capture* dynamics is crucial for collaboration (CHESBROUGH; LETTL; RITTER, 2018; DYER; SINGH; HESTERLY, 2018), especially in a digital servitization context (VISNJIC; NEELY; JOVANOVIC, 2018). According to Zott and Amit (2010) and Dyer *et al.*, (2018), the creation of value is related to the boundary-spanning nature of a company's business model, in which the required activities are performed outside the boundaries of a focal firm, collaborating with partners, suppliers or customers. Thus, inter-firm value creation is a function of complementary resources and joint activities between partners (AYALA *et al.*, 2020). The value created within collaborative arrangements have two distinct perspectives: the *value in use* and *value in exchange* (EGGERT *et al.*, 2018). Value in use refers to the deployment of resources within activities oriented to a specific

outcome, in which the resource will have a predominantly subjective value according to its utility to the receiver. Value in exchange refers to a trade of resources among actors, where the provider negotiates its access to the receiver. In this case, the resource is reflected in market price with an objective conceptualization (CHESBROUGH; LETTL; RITTER, 2018; EGGERT *et al.*, 2018). When partners engage in joint activities to develop a focal value proposition, the collaboration has an underlying *ecosystem-as-structure* logic, focused in the alignment of activities among the partners. If the partners interact with each other to have access to new resources and competences without a focal value proposition, the collaboration has an underlying *ecosystem-as-affiliation* logic, more focused on the community enhancement and not in the creation of specific value propositions (ADNER, 2016). For *value capture*, the bargaining power between actors will determine the extent to which each actor can appropriate the common benefits of the collaboration outcomes (BOWMAN; AMBROSINI, 2000). In this context, value capture will be a function of the complementary resources, which in this case represents resource interdependence. The more distinct an actor's resources, the more that actor stands to benefit from collaboration. Thus, this dimension is related to the inimitability of resources and power-related aspects, such as position in the supply chain (BARNEY, 2011; DYER; SINGH; HESTERLY, 2018) and shared interests. Partners with similarities of interests act in similar markets and customers, possibly being competitors, oppositely of partners with differences of interests. The former seek to capture value related to communication blockages of its business, while the latter seek for tradeoffs to create mutual benefit (LAX; SEBENIUS, 1986; ZAJAC; OLSEN, 1993). The degree of interdependence of the actors will determine the governance mechanisms of the collaboration. Formal governance, represented by contractual mechanisms, is usually present in inter-firm agreements to dictate each actor's engagement and to safeguard the desired value appropriation. However, studies show that informal governance mechanisms are fundamental for inter-firm joint activities (SANTORO; BRESCIANI; PAPA, 2020; WU; CHUANG; HSU, 2014), where trust is the primary element to incentivize joint efforts and create value with other partners (DYER; SINGH; HESTERLY, 2018; SAKO, 1997).

Different configurations of collaboration are possible in the servitized business models when value creation and value capture are considered. This means that external partners can be useful for value creation, value capture, or for both (MORGAN; FELLER; FINNEGAN, 2013; TANGPONG *et al.*, 2015). In this sense, we propose the framework represented in Figure 4.1

to describe these different patterns of collaboration in digital servitization and their relationship with value creation and value capture of the servitized business model. The proposed patterns are based on previous studies from Dyer, Singh, and Hesterly (2018), Gebauer et al. (2013), Morgan, Feller, and Finnegan (2012), Tangpong et al. (2015) and Pathak et al., (2014). On the X-axis, we indicate the level of *value creation* joint activities between the key actors involved in digital servitization (i.e. product firms, service providers, and digital technology supplier). The Y-axis represents *value capture* interdependence. Both axes represents qualitatively a range from low to high focus on these two business model dimensions, enabling a comparison between the different arrangements proposed in terms of the relative integration and interdependence within the value network. The combination of these intensities of value creation and capture configurate four generic patterns or arrangements of inter-firm collaboration for digital servitization, named *Expanded business*, *Enhanced business*, *Platform business*, and *Symbiotic business*, as we explain next.

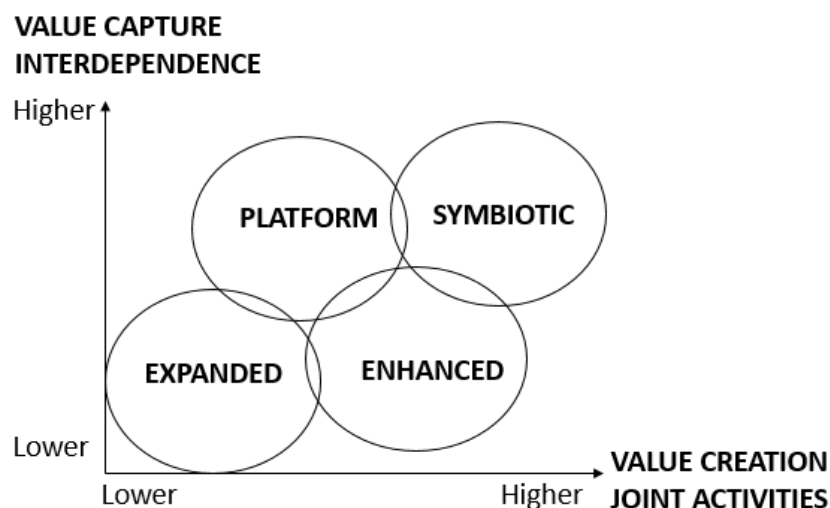


Figure 4.1 Inter-firm collaboration types for digital servitization

4.2.1.1 EXPANDED BUSINESS

Expanded business represents a collaboration with low engagement of the actors for value creation joint activities and low value capture interdependence. This collaboration type is presented as Collaboration 1 in Figure 4.2, and is the least integrated of the four types. This collaboration type is the closest to the community collaboration proposed by Pathak et al., (2014) and the collaborative transaction management of Whipple and Russell, (2007), in which companies create an ecosystem-as-affiliation with no high dependency in the collaboration, but they exchange operational information to support business in related markets. In this

collaboration, each actor has an independent value proposition for the customer, but their relationship brings benefits through the expansion of their business model. This concerns a new trend in business models within IoT ecosystems: the data is collected by the focal firm from the digital service solution and sold to an external actor that can use it to improve its products or deliver additional services (BURKITT, 2016). Data can be sold without significant addition of value, or it can be combined with other sources and with analytics (DELOITTE, 2014). This type of collaboration can occur directly between the product firm and the external actor, as shown in Variation 1A (Figure 4.2), or through intermediate actors, as represented by Variation 1B (Figure 4.2) (BURKITT, 2016). It has lower levels of joint activities for value creation and lower value capture interdependence since the data is necessary only for one actor's business, representing unilateral dependence. The sale of data is not essential for the focal firm's business model, merely representing an expansion of its revenues.

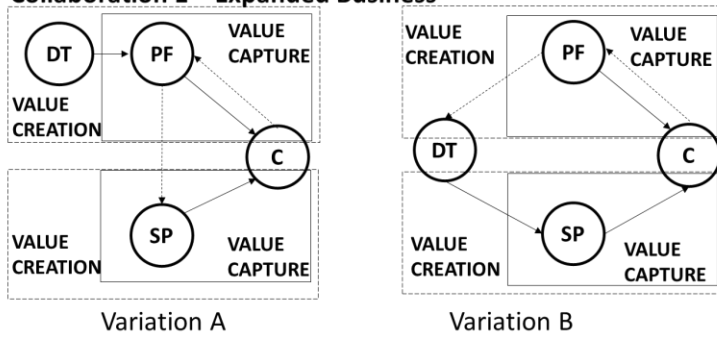
4.2.1.2 ENHANCED BUSINESS

As shown in Figure 4.2, the *Enhanced business* refers to a collaboration with high engagement for value creation joint activities but low value capture interdependence involving the digital servitization of a focal firm (Variation 2A). The product firms can also participate in a digital solution offering, but as suppliers of a service provider (Variation 2B) or of a digital technology supplier (Variation 2C). This type of collaboration has unilateral dependence, with the focal firm depending on its suppliers (TANGPONG *et al.*, 2015), forming a hierarchical collaboration with joint planning activities for new product development within an ecosystem-as-structure (ADNER, 2016; PATHAK; WU; JOHNSTON, 2014; WHIPPLE; RUSSELL, 2007) to a greater extent than the previous arrangement. This collaboration follows a classic supply chain configuration, in which the actors provide their solutions to one actor, who delivers the value to the customer. Thus, upstream partners have no interaction with the end customer but have strong interactions with the focal firm, with high knowledge-sharing routines and high investments in relational assets. This type of collaboration for digital servitization is illustrated in the case study of Saarikko *et al.* (2017), in which a manufacturer of washing machines aimed to add digital capabilities for product monitoring to enable further digital services. The product firm collaborated with two digital technology suppliers, for connectivity, cloud services and data management. The solution was developed through joint activities between the product firm and the two suppliers, whose input enabled the servitization of the product firm's business model.

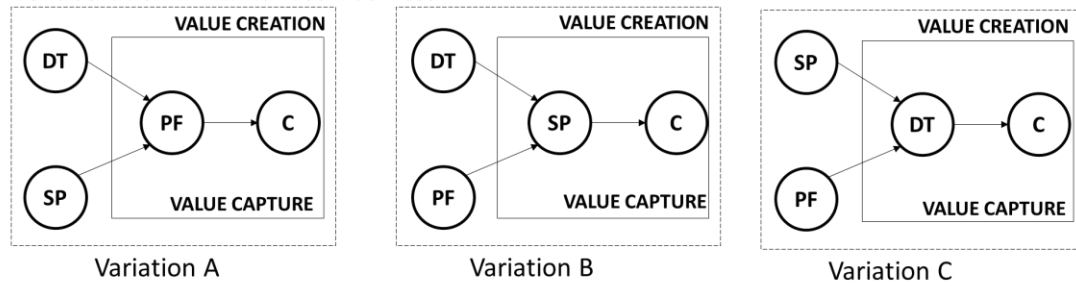
4.2.1.3 PLATFORM BUSINESS

Platform business is collaboration with high levels of value capture interdependence but low requirements for joint value creation activities. In the context of digital servitization, this collaboration supports the development of complex solutions requiring a platform approach (CENAMOR; RÖNNBERG SJÖDIN; PARIDA, 2017; ELORANTA; TURUNEN, 2016; KAPOOR *et al.*, 2021). The platform concept is based on a foundation of products, services, and/or technology for external actors to develop innovative complementary value (BENITEZ *et al.*, 2021, 2020; GAWER; CUSUMANO, 2014), such as the Federation collaboration of Pathak *et al.* (2014). This approach enables actors to be connected, sharing resources and integrating systems in a synergic way in an ecosystem-as-affiliation approach (ADNER, 2016; ALLMENDINGER; LOMBREGLIA, 2005), and is a viable solution for them to complement their offerings and increase both their value creation and their value capture (KAPOOR *et al.*, 2021; TIAN *et al.*, 2021). One example of the platform approach, as shown in Variation 3A (Figure 4.2), is the smart home concept, HomeKit, from digital technology company Apple (APPLE, 2020). HomeKit is a multi-actor platform business model with a network effect, with each actor providing a connected product for the platform, thereby increasing customer perception of the platform's value, which in turn benefits all the actors involved. The platform centralizes the digital services of connected products from other firms, such as smart lamps and smart thermostats. Once a product firm has registered for a license, Apple supplies protocol specification, testing tools, guidelines, logo artwork, and, ultimately, certification, provided the product conforms to the criteria required. The certification and Apple's guidance allow products to be easily integrated into the platform, without any requirement for joint activities by the parties (FEILER, 2016; FIFIELD, 2020). A platform may also be product-based (Variation 3B), as exemplified by the OnStar digital platform of services for cars (WILLIAMS, 2007).

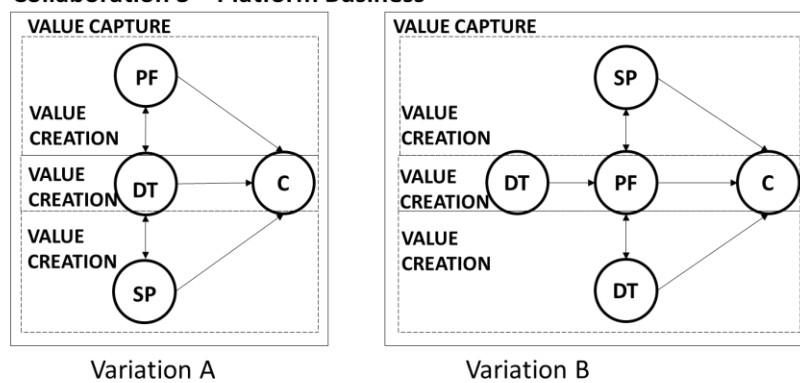
Collaboration 1 – Expanded Business



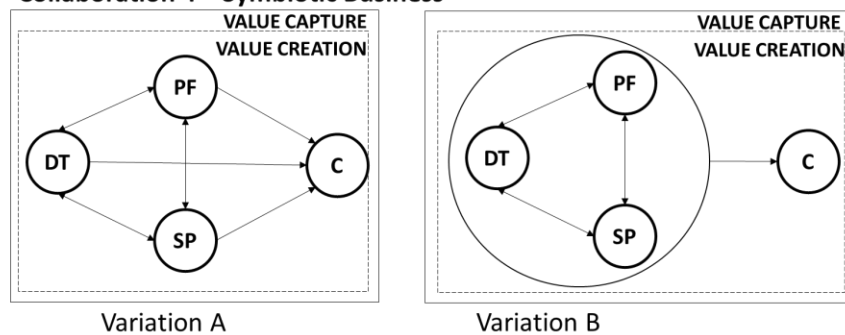
Collaboration 2 – Enhanced Business



Collaboration 3 – Platform Business



Collaboration 4 – Symbiotic Business



Legend:

- PF = Product firm
- C = Customer
- SP = Service provider
- DT = Digital technology supplier
- = Exchange of resources and capabilities
- ⋯→ = Exchange of data and information

Figure 4.2 Interaction among actors in the four collaborations types for digital servitization

4.2.1.4 SYMBIOTIC BUSINESS

The final collaboration type is characterized by high value creation joint activities and high value capture interdependence, which we name as *Symbiotic business model*. This type of collaboration has a strategic/bilateral partnership, characterized by joint decision-making (TANGPONG *et al.*, 2015; WHIPPLE; RUSSELL, 2007), in which companies belonging to multiple competing supply chains join in consortium with an ecosystem-as-structure approach (ADNER, 2016; PATHAK; WU; JOHNSTON, 2014). Unlike Platform business, this collaboration has high investments in relational assets by each partner, as they engage in activities ranging from engineering to after-sales. The actors seek a win-win relationship, in which all of them rely on the efforts of their partners to ensure the viability of their business, leading to a long-term partnership in the form of co-business with a highly integrative nature. The partnership between Apple and Nike for the Nike+ business segment is an example of this collaboration type because, through sensors embedded in Nike shoes, the shoe manufacturer is able to offer digital services to customers with information on running performance, and other functionality, through Apple's iPhones. Both companies have remained with their core businesses but have developed synergic value from their combined solutions, which increases customer perception of the value of both companies' offerings (RAMASWAMY, 2008). This case is represented by Variation 4A (Figure 4.2), in which each company provides its own offering separately. When an offering is bundled in a joint-venture collaboration, such as the Car2Go car-sharing service, which originated from a joint venture between Daimler and Europcar (BUSINESS WIRE, 2018), this corresponds to the Variation 4B (Figure 4.2).

4.2.2 SOCIAL EXCHANGE THEORY AS A LENS FOR INTER-FIRM COLLABORATION FOR DIGITAL SERVICIZATION

As shown above the inter-firm collaboration types can be defined in terms of value creation and value capture. Such characteristics describe *what* the actors aim to achieve with the business model followed in ecosystem. However, this does not explain *how* the interactions between the ecosystem's actors happens. Therefore, we follow the Social Exchange Theory (SET) to investigate empirically the interaction patterns that are behind each of these different inter-firm digital servitization configurations.

SET has been previously studied in the servitization context (e.g., BASTL *et al.*, 2012; KARATZAS *et al.*, 2017; SACCANI *et al.*, 2014) as it enables a detailed understanding of the

primary interaction factors between external actors who influence value creation and value capture (Benitez et al., 2020; Tanskanen, 2015; Wu et al., 2004). According to Emerson (1976), this theory examines the social exchanges between actors, their long-term relationships, and how the exchanges increase positive outcomes. Their relationships are seen as a form of structured relational dependence, determining the behavioral patterns of the exchanges between the parties who act upon the expectation of reward from the other parties (EMERSON, 1976; MOLM, 1997). Thus, SET highlights value creation from collaborative relationships based on trust and reciprocity, and not on contractual agreements (HOMANS, 1974; MERMINOD; LE DAIN; FRANK, 2021; TANSKANEN, 2015). According to Wu et al. (2014), *trust* and *reciprocity* together with *power* and *commitment* comprise the four elements that define interactions in SET and are important in determining the value appropriated by each actor involved.

The first element of SET, *Trust*, considers the willingness of one actor to rely upon another. With trust as a basis, companies are open to exchanging information, knowledge, resources, and capabilities with each other, increasing the possibilities for further value creation (CORSTEN; KUMAR, 2005; CROPANZANO; MITCHELL, 2005; YANG *et al.*, 2008). According to Sako (1997), trust between companies can be classified into three levels, ranging from low to high depending on requirements, subsequently: contractual trust – a shared moral norm of promise-keeping; competence trust – a shared understanding of conduct for technical and managerial support, and goodwill trust – a shared consensus of fairness. While trust is necessary for companies to be open to cooperation, *Reciprocity*, the second element, incentivizes them to put effort into the relationship (WU *et al.*, 2004). According to Cropanzano and Mitchell (2005), reciprocity is repayment in kind, and can be represented as a transactional pattern of interdependent exchanges. The actors have a reciprocal exchange, in which whatever is given is returned with the same level of appreciation, creating interdependent outcomes where both parties must combine their efforts. Oppositely, nonreciprocal exchanges create independent or dependent outcomes, in which one party provides the entire effort of the development, the focal firm or the partner, respectively (CROPANZANO; MITCHELL, 2005; MOLM, 1997). Reciprocity may also be governed by an expectation of fairness, or some other cultural norm, with the possibility of sanction (GOULDNER, 1960). Thus, *Power*, the third element of SET, considers how one actor can influence the efforts and decision variables of the others (DAHL, 2007). The supply chain may have a power imbalance, where one actor is less

dependent than another, since the exchanges favor the former (MOLM, 1997; WU *et al.*, 2004). Different factors determine the balance of power and the firm's position in a network, mostly comprehended within organizational level and relational level, the two main sources of power. The resources, capabilities, firm's size, brand and other sources represent the organizational level of power, while inter-firm information sharing represents the relational level of power sources (KÄHKÖNEN; VIROLAINEN, 2011). Finally, long-term relationships should have a high degree of *Commitment* from the actors, which is the fourth element of SET and represents actors' belief that a relationship is worthwhile and that they should invest maximum effort to maintain it, thereby bringing long-term stability (WU *et al.*, 2004; YANG *et al.*, 2008). Exchanges with higher degrees of commitment have actors willing to make sacrifices and to spend more time and effort with each other, aiming for the continuity of the relationship (MORGAN; HUNT, 1994; WU; CHUANG; HSU, 2014).

SET has been widely used as the basis for collaboration studies of supply chain management, providing important insights (BASTL *et al.*, 2012; SACCANI; VISINTIN; RAPACCINI, 2014). For instance, in the context of digital technologies, Benitez *et al.* (2020) analyzed the way in which a group of companies evolved into a collaborative ecosystem in order to develop advanced technological solutions. By analyzing trust, commitment, power, and reciprocity, the authors established, for example, that the presence of a neutral coordinator helps to create a balanced power structure, reducing suspicion of opportunism between the companies and increasing mutual trust. Similarly, Bastl *et al.* (2012) used the SET lens to analyze the servitization context, showing, among others findings, that trust-based safeguarding mechanisms are essential for closer collaboration with key suppliers for a servitized offering. Thus, both studies demonstrated that the elements of SET are fundamental for the analysis of collaboration in servitization and digitalization contexts, since collaborations with a higher level of relational attributes can result in higher levels of engagement by the parties. However, as presented above, and suggested by Tangpong *et al.* (2015), different types of collaborative interaction can be configured according to the actor's needs. A focal firm undergoing a digital servitization process can choose to collaborate with several actors with lower levels of trust and commitment or with a few actors in closer engagements. Thus, an understanding of the implications contingent on the different types of collaborations in terms of the SET elements is essential for product firms, since this choice can have long-term effects and its success could be limited by the correct management of the different elements.

4.3 RESEARCH METHOD

Based on the collaboration theories, the objective of this paper is to understand the dynamics of the proposed collaborations. By analyzing the SET elements in different types of collaborations for digital servitization, we can capture the nuances of the complex relationship between the actors involved and shed light on how companies can explore this alternative to tackle the challenges of digital servitization. As little is known about the topic, a qualitative case study approach is the most appropriate method for exploring this phenomenon. Therefore, we used the case-research method for theory building (EISENHARDT; GRAEBNER, 2007). We took a multiple-case approach (YIN, 2014), conducting one case study for each quadrant of Figure 4.1. We aim to analyze the SET elements in different types of collaborative relationships in digital servitization, examining the dynamics of inter-firm value creation. The case studies were conducted in accordance with the guidelines of Voss et al. (2002), as described below.

4.3.1 CASE STUDY SELECTION

Case studies were selected according to a theoretical sampling approach, meaning that they were selected due to the suitability to explain the constructs (EISENHARDT; GRAEBNER, 2007). The first step was therefore to identify companies within the context of this research. We chose companies within different businesses and offered services, in which we selected cases that enabled a clear identification of the servitized offering and the relations with external firms, allowing a comparison with the different collaborative configurations. We selected companies to which we could have access with the most appropriate parties to interview, i.e., managers related to the service provision of the offerings, procurement, and marketing. In addition, for the cases in consideration, all interviewees already participated in previous research with at least one of the three research facilities of the authors. We conducted interviews with companies that play a key role in collaborative Smart PSSs, in which we identified and selected four of them as the most suitable cases to the purpose of this study and that shows differences between them, allowing us to categorize in the four predefined configuration types. In Table 4.1, we show the four selected case studies for this article.

Table 4.1 Case studies for the research

Collaboration type	Company	Description	Sources
Expanded business	ElectricCo	Multinational manufacturer specialized in electrical distribution (products and services)	1 procurement manager (2 interviews) and 1 marketing director (1 interview)
Enhanced business	MoldCo	Multinational manufacturer for molds development and assessment	1 sales manager and 1 R&D engineer (2 interviews with both)
Platform business	IndustrialCo	Multinational supplier of digital solutions, automation and electric distribution for industries	2 managers of cloud applications solutions (1 interview with each)
Symbiotic business	AutomationCo	Multinational supplier of automation solutions in sensors, software integration and machine vision	1 CEO of regional subsidiary (2 interviews)

4.3.2 RESEARCH INSTRUMENTS AND DATA COLLECTION

In order to collect data to analyze the relationships, we conducted semi-structured interviews with the abovementioned companies, following an interview guideline (Appendix A). These interviews were divided into two parts. For most of the case studies, the two parts were conducted on separate occasions although with the same interviewees. The first part of each interview consisted of questions on: (i) general information about the company's business; (ii) details about their offerings, including identification of the products and services of which these were comprised, and how they were enabled by digital technologies; (iii) types of revenue and relationships with customers; (iv) the relationship with suppliers and how the company engaged in collaboration with them. After analyzing the possible collaboration with suppliers according to the product firms' offerings, we proceeded to the second part of the interview. We posed questions about the relationship with their suppliers and other external companies, including a general description of the relationship, the frequency of interaction with them, their expected capabilities the type of agreement and questions about the SET elements, and its outcomes. Thus, for each important actor in the collaboration, we asked one question for each of the SET elements, plus the expected rewards and outcomes. In all questions, we asked the interviewees to provide arguments and examples to evidence their answer.

Data was collected from multiple information sources to ensure the reliability of our analysis (YIN, 2014). Before the interviews, we gathered information about the companies from their websites and reports, in particular with regard to their offerings and investments in the areas of service development, digital technology acquisition and development, and their partnerships within these contexts. Following the guidelines of Voss et al. (2002), all interviews were recorded and notes were taken by the researchers. For those interviews conducted via online videoconference, a feature of the application was used to make the recordings. In the other cases, an audio recorder was used. All interviews were transcribed by the authors. We also collected data from internal company documents such as project presentations and reports.

4.3.3 DATA VALIDITY, RELIABILITY, AND ANALYSIS

Deriving information from a range of sources resulted in data triangulation, which supported construct validity according to Voss et al., (2002). As previously explained, we structured our questionnaire to segment the transcribed data into each analyzed construct. Four researchers validated the questionnaire. After gathering the transcribed data with information from other sources, we then highlighted the important parts of the interview transcripts before collating the data into predetermined categories for the company's digital servitization, its type of collaboration with external suppliers, value exchanges and SET elements. Five researchers participated in the meetings to conduct this process. For validation, we also crossed data with case studies from the literature, which could corroborate our findings and highlight differences from other contexts. To ensure reliability, we used constructs based on the literature on collaboration and followed a case study protocol, as outlined below.

In Step 1, we conducted online research about the companies through articles and websites to identify their servitized offerings. In Step 2, we conducted the first part of the interview to identify the type of collaboration the company has with suppliers or other actors. Step 3 was the second part of the interview, including identification of the value exchanges, rewards and the SET elements for each collaboration (for the Platform and Symbiotic cases, Steps 2 and 3 were conducted at the same time because of the availability of the interviewees). The Step 3 was repeated for each relationship with a considered important actor, which means that we focus on each important dyad that compose the network, and repeated the questions as necessary. Step 4 consists in the data analysis, in which each case in line with the conceptual framework. According to the case study configuration, we gathered all the notes from Step 3

and proceeded to the identification of elements with each of the actors in collaboration, based on a content analysis. Each question of Step 3 is considered a label for each one of the elements (value exchange, value reward, and the SET elements). First, we selected the statements that described each element in the dyad, and then we highlighted and grouped the terms according to their meanings and links to the predefined labels. The meanings were the definition of the elements presented in Section 2. To validate this step, we crosschecked information among each of the elements. For example, reciprocity and power may have closely linked dynamics, once the expectations of each actor will motivate relational investments that alter the power dimension in the relationship. Therefore, we compared each information to each element, to confirm the categorization of the elements. Finally, Step 5 was a cross-case analysis of the results, highlighting the differences of each type of collaboration: findings from the different cases were compared in order to identify distinctive patterns, while similar cases from the literature were also examined in order to provide further insights.

4.4 RESULTS

4.4.1 CASE STUDIES' ANALYSIS

This section contains the case studies for the proposed typology, described in Table 4.2. Figure 3 shows the collaborative configuration of each case study, with the results summarized in Table 4.3. We discuss each of these arrangements identified next.

4.4.1.1 EXPANDED BUSINESS (ELECTRICCO)

In the area of electrical distribution, ElectricCo usually sells products intermediated by electricians, the service providers for electrical installations. Thus, ElectricCo is in an upstream position in the supply chain, as represented in Figure 4.3A and the Variation 1A of Figure 4.2. In order to form a closer connection with its end customers, ElectricCo developed a Smart PSS, which brings the prospect of benefits beyond its core business: the generated product data can be used for new collaborations, to expand the business model and become a data provider, as mentioned by the marketing director: *“This strategy is important since the digital solutions bring actors of the ecosystem closer to each other, even when no product or service transactions between them are required”*. ElectricCo considers selling this data to external actors, such as insurance companies, as the marketing director mentions: *“(…) it’s a win-win situation, they (the insurance companies) are interesting in the level of safety of the power*

installation, and now we are able to provide data to support this". Thus, insurance companies can use this product data to improve their predictions about power distribution safety. ElectricCo has no dependency on this type of revenue, which represents an additional revenue source for its business model, increasing the importance of its position in the supply chain. As dependency lies with the data buyer, this type of relationship represents a low value capture interdependence. In addition, the mere provision of data represents lower levels of joint activities, indicating low value co-creation.

Table 4.2 Case studies description

Collaboration type	Business	Smart PSS	Collaboration description	Arrangement type
Expanded	Electric distribution	Connected switchboards with digital services that use energy system data to provide real-time and predictive information of electricity distribution on the customers' buildings.	Provision of customer data to third parties (insurance company), which provides services to the same customer.	Triad
Enhanced	Molds for plastic injection	Molds (for plastic components industry) with digital and intelligent features that improve the performance metrics of the customers' process with cost-reduction in service provision and improvement in product quality.	Co-development of smart molds with a supplier with expertise in sensors, IoT connectivity modules and infrastructure, and artificial intelligence	Diads
Platform	Industrial process digitalization	Cloud-based platform with IoT open standards that provides industrial customers with access to a wide variety of digital applications (related to products, machines and industrial processes).	Open platform with external developers to offer flexible solution to the customers.	Network
Symbiotic	Industrial automation	Complete machine vision solution, with commissioning services.	Co-development of more advanced machine vision solutions with machine manufacturers and system integrators)	Network

Regarding the social exchange elements that help to define this configuration, we observed in the interviews that making the data collected available to external partners requires a level of *mutual trust*, since any leakage of customer data could significantly damage the company's brand reputation. However, the issue of trust can be addressed simply through contractual mechanisms for data concerns, without any requirement for expertise or goodwill from the partner. Furthermore, collaboration is more beneficial in an agreement where there is *long-term commitment*, as the continuous provision of data enables further insights and better predictions for companies like insurers, while the data provider gains greater revenue as a result. However, the companies have a low level of interaction, with no requirement for any specific relational assets for the collaboration as mentioned by the marketing director: "*We already knew their*

existence in our ecosystem, and that we had this data they could use. Now we have this relationship with them and maybe in the future, it can be stronger, but for now is only about exchanging information”. Thus, despite the willingness to maintain a long-term relationship, the collaboration has a low degree of *commitment*, as no actor shows willingness to make sacrifices nor to spend time and efforts in the relationship. Because the actors see the outcomes of the relationships as additional benefits, rather than being fundamental to their core business, levels of *reciprocity* between them are low, which means there are low expectations on both sides of the relationship as both actors are independent of the relationship. Since the data provider has no dependency and has more *bargaining power* than the data receiver, then *power* is tipped in favor of the product firm. However, the dependency is not high, as the insurance business was not developed on the basis of the data, which represents a collaboration based only on *relational power* sources.

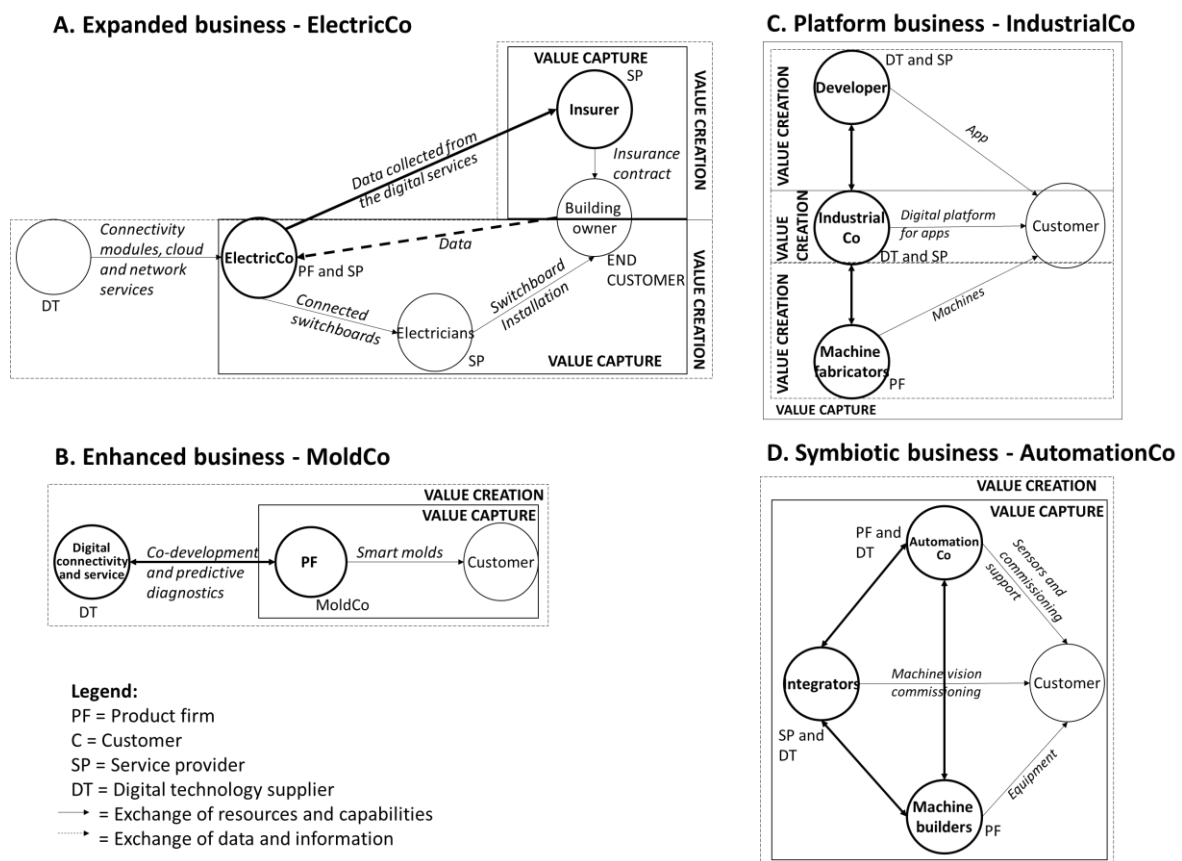


Figure 4.3 Case studies configurations of the typology

4.4.1.2 FOCAL FIRM ENHANCED BUSINESS – MOLDCO

The case chosen for the *Enhanced business* collaboration has MoldCo as the focal firm, as represented in Figure 4.3B and the Variation 2A of Figure 4.2. The smart mold provides a cost-

reduction in service provision, improvement in product quality and the customer process, and a reduction in the energy consumption of the customer process. This offering is a highly innovative solution for the company and the market, requiring a close working relationship with the digital technology supplier: during the six-month solution development process, the two companies usually interacted on a daily basis. Unlike the previous type of collaboration, Enhanced business is marked by joint activities and a close relationship between companies, to develop new capabilities for the buyer, such as product monitoring, predictive diagnostics, and remote support. According to the interviewees, regarding the social exchange elements, *trust* was important since they were sharing MoldCo's expertise to develop the solution, as the smart mold has specific actuators for quality sensors and control of the mold. Thus, *trust*, at least in terms of competence, was a requirement for the relationship. With regard to the *commitment* required, the interviewees consider a long-term engagement as the sales manager mentioned, "(...) *Everything is managed by [MoldCo] directly with the customer. For example, if you access our online system, it is our own logo, but this system is powered by another company (digital technology supplier) using artificial intelligence. With this provider we have to work with them all along the life of the product, because for the artificial intelligence we need to make them evolve all along the life of the product. We are engaged for life*", since continuous support from the supplier would be necessary for the predictive diagnostics of MoldCo's service provision. However, this support was more frequent in the development phase, changing to ad-hoc support once MoldCo had delivered the offering to the customer. Thus, this collaboration shows a medium-high degree of *commitment*, as actors are willing to make sacrifices, to provide time and effort in order to keep the relationship. However, regarding *reciprocity*, the exchanges have a dependent orientation of the product firm. The expectations on the buyer's side were high, as the supplier's efforts were essential for the development of innovation and capabilities, with the buyer's reward being the solution. On the supplier's side, expectation was low, since, although the new solution gave access to a new market, allowing the supplier to grow its customer service provision, this was not fundamental to its own business. Neither side had clear *bargaining power* in the relationship. Despite MoldCo's dependence on the supplier's capabilities, the interviewees noted that there were other suppliers on the market equally capable of developing a similar solution. They also perceived the small size of the supplier's company as beneficial to them, as the sales manager mentions: "(...) *they are a small company, giving us more support than big companies (...). These ones would not be interested in providing the same levels of effort*".

4.4.1.3 MULTI-ACTOR PLATFORM BUSINESS – INDUSTRIALCO

As shown in Figure 4.3C and in the Variation 3A of Figure 4.2, IndustrialCo promotes a common platform, with internal and external developers offering digital applications to industrial customers. The platform works with a model based on annual licenses, in which customers buy and use the developers' applications available. The solution is also of interest to device manufacturers, who can provide digital applications for their devices on the platform. The platform has basic applications developed by the company, but the biggest advantage is the availability of external applications to the users. In this way, IndustrialCo offers an innovative solution to the market with great flexibility, since joint activities with customers or external developers are not required. However, this leads to increased dependence on external developers in order to make the platform more attractive to customers.

According to the interviewees, the dynamics of the platform mean there is no requirement for *informal trust* mechanisms, because the contractual mechanisms are enough: “*We don't have a relationship with these external developers. They sign to the platform, offer their services and in many times, collaborate with the customers, but we have no interference in their business*”. The company does not intermediate the sale of the apps between developers and customers, instead capturing revenue from the license fees paid by the users. Licenses to access the platform last for one year, after which users can choose whether to renew. However, a license must be renewed in order to keep an application running, and the interviewees stated that, to date, almost all users have renewed their license. Thus, the actors show a low degree of *commitment*, as there is no sign of willingness among the parties to dedicate time and effort in the relationships, even though these tend to long last. In terms of *reciprocity*, by developing an open platform, IndustrialCo now has a large network of users – developers and customers – which allows the company to remain independent of individual companies. However, the platform requires a network of users for its success, so the company is dependent on them. The interviewees mentioned that, although the developers and customers are not dependent on the platform for their business, there is no comparable solution on the market, so customers would not otherwise have these digital services available to them: “*We are the first one to offer a complete solution. We know some competitors offer other types of platform, but with limited applications*”. In addition, the platform works with several different industrial protocols, supporting the digital transformation of Industry 4.0 initiatives for customers. Thus, in terms of *reciprocity*, the exchanges are interdependent, although in a low degree.. Lastly, since there

is no other solution as complete as IndustrialCo's offering in the market, the company has greater, although not high, bargaining power. *Power* is tipped in favor of the digital technology supplier, based on both organizational power and relational power sources, as the platform provides an efficient access to the customer for service provision

4.4.1.4 SYMBIOTIC BUSINESS – AUTOMATIONCO

In the machine vision business, the company, providing the sensors and supporting commissioning of the solution, jointly provides the solution to the customer with the machine manufacturers, as—the interviewee describes collaboration as taking place within a “(...) *magic triangle, where there is the knowledge provider, the machine builder, and the end-user*”. For more advanced solutions, especially for customers in the life sciences sector, AutomationCo must also collaborate with specialized system integrators who provide more advanced software in machine vision technology, carry out the installation on the customer's site, and are responsible for the functioning of the system. This case is therefore symbiotic, as all actors need each other's resources to create and capture value from the customer, with each actor offering their solution to the customer, while remaining integrated with the others. This collaboration is shown in Figure 4.3D and in the Variation 4A of Figure 4.2.

The Symbiotic business of AutomationCo is a collaboration resulting from a market requirement for the solution. Cooperation with the other companies occurs mostly for more advanced machine vision solutions. In this business, the actors are interdependent, although they did not create the business model together. According to the interviewee, “*Trust is essential for this business, in order to create a safe environment for joint activities, sharing information and resources, also because of the data security issues*”. The relationship is marked by a long-term partnership among the companies, in which the actors are willing to invest in the relationship to continue their business and expanding to new markets, showing a high degree of *commitment*. Given the highly interdependent exchanges, *reciprocity* is high, as all actors have high expectations of each other's effort. Regarding *power*, the interviewee states that for the most advanced machine vision solution, they are increasingly dependent on specific systems integrators with dedicated software: “*Some system integrators offer more advanced types of software, and some customers in industries such as life sciences will give priority to these actors, leading machine builders and sensor providers to become more dependent*”. Thus, the balance of *power* is seen to favor the system integrators.

4.4.2 SOCIAL EXCHANGE PATTERNS FOR DIGITAL SERVICIZATION

Our findings allow us to identify different patterns of social exchange activities that differentiates the configurations of inter-firm collaboration in digital servitization ecosystems. We found that each configuration can be defined by two characteristics: the combination of value creation and capture, which defines *what* is the business model, and the combination of the four elements of the SET (trust, commitment, reciprocity and power) that show *how* the interactions between the ecosystem's actors happens. The elements identified in SET are summarized in Table 4.3 and the different patterns are explained next.

The *Expanded* business represents a collaboration with low joint-activities for value creation and low-value capture interdependence. In this case, the exchanged resource is information about product-related services, which does not demand intense interactions in joint-activities. Relation-specific investments are not present in this type of collaboration, resulting in low informal trust mechanism requirements. Only contractual mechanisms of *trust* are required because external parties need to access internal data from the company and the customer. Security issues are an inherent challenge of digital offerings, being cybersecurity an increasing concern. In this context, the demanded *trust* is not necessarily implied in opportunistic behavior from the other party. However, for this type of collaboration, the company must also feel confident about its partner's data security. The companies form a strategic relationship with low-degree of *commitment* to expand the existing business, resulting in a network with low *reciprocity*, in which the expectations are limited to a firm that requires a complementary resource or information from another firm, but are not dependent on it. The rewards are new revenues and more *power* to the servitized company. Prior research has stressed the importance of data for the future of business models, with some companies interested in acting as a data provider and having a central role in the ecosystem, creating dependency among other actors on the company (BHARADWAJ *et al.* 2013; DELOITTE 2014). Thus, we developed the following proposition:

Proposition 1: Expanded business is a type of collaboration among partners that requires low degrees of trust, commitment, reciprocity, and power. Collaboration can be unbalanced, favoring one partner over the other, but power is not a defining mechanism of the relationship, being one of the drivers of this type of collaboration, based entirely on relational sources of power

Table 4.3 Summary of the results

Collaboration type	Value creation	Social Exchange Theory (SET)				Value capture
		Trust	Commitment	Reciprocity	Power	
Expanded business	Data for third parties	Contract	Low Degree	Independent exchanges	Relational - Imbalanced	Additional revenues
Enhanced business	New solution development	Competence	Medium-high degree	Dependent exchanges	Organizational and relational - Balanced	Innovation and capability development
Platform business	Flexible solutions	Contract	Medium-low degree	Medium interdependent exchanges	Organizational and relational - Balanced	Innovation, capability development, access to new markets and cost-reduction
Symbiotic business	Development of more advanced solutions	Goodwill	High degree	High interdependent exchanges	Organizational and relational - Imbalanced	Innovation and access to new markets

On the other hand, *Enhanced business* has joint-activities for value creation. Companies share information regarding customer process-related services, developing relation-specific assets that require more interactions among the actors, and informal trust mechanisms. However, this collaboration is marked by unilateral dependence and medium level of *reciprocity*, not requiring a goodwill level of *trust*. The companies form a *commitment* due to a technical need, with the product firm retaining a cooperation agreement to have support from a partner to improve the efficiency of an existing business. As the servitized company also relies on the partner's solution for the after-sales phase of the digital servitization life cycle, collaboration demands a long-term commitment with event types of interactions. This partner is no competitor in the market, not requiring the servitized company to rely on strong power mechanisms to obtain more benefits. However, *power* is more important in this type of collaboration than the *Expanded business*, as the servitized company has the dependence on the partner's resources and expertise. We developed the following proposition:

Proposition 2: Enhanced business is a type of collaboration with moderate requirements of *trust*, *reciprocity*, and *power*. The digital servitized company might require a strong *commitment* from the partner, but not the opposite, creating unilateral dependence of the business.

The *Platform* business is a strategy to create value with other companies without joint activities, becoming dependent for value capture. This dynamic reduces the need for informal *trust* mechanisms, requiring only contractual mechanisms for the same reasons as the *Expanded* business. The platform approach requires the companies to have access to the platform in order to profit from it, but these are free to stop using it at any moment, demanding a low degree of *commitment* of the users. This type of collaboration is a trend for digitalized environments, in which companies can autonomously develop their Smart PSSs that are complemented with solutions from other product firms, digital technology suppliers, and service providers. The network has a medium degree of *reciprocity*, as the exchanges have some degree of interdependence, in which the platform is valuable with actors' engagement, but a significant number of actors is available. *Power* can be determined by the strategy of the digital platform provider: open or closed-source (JOVANOVIĆ; SJÖDIN; PARIDA, 2021). In closed platforms, the company has more control of the solutions incorporated in the platform, providing more differentiation to the customers. However, in open platforms, many players can be engaged, offering more solutions to the customers and reducing specific companies' bargaining power. Considering this, we developed Proposition 3:

Proposition 3: Platform business is a type of collaboration with low trust and commitment requirements. Due to the type of engagement, partners can adopt several options, reducing the reciprocity to a medium level. Power will be determined by organizational and relational sources, especially in function of the platform's dynamics, in which open-source platforms have more balanced power.

Lastly, *Symbiotic* business is the most integrative type of collaboration, consisting of exchanges regarding customer process-related services. This collaboration requires higher levels of informal *trust* mechanisms with high relation-specific assets and bilateral dependence for value creation and value capture. The *commitment* is long-term oriented, usually with continuous interactions among the engaging partners that shared operational linkages through their combined solutions. The *commitment* has a technical and strategical driver, as the companies involved create an interdependent ecosystem, with high *reciprocity*, to provide a more advanced solution to their customers, developing new activities and/or new business models. The dependence is defined by many factors, in which in digital servitization, the innovative degree of the solution is an important determinant for the *power* dynamics. Among

all types of collaborations, *power* is more determinant in the symbiotic business, as the engaged actors can also be competitors in their markets. Thus, we developed the following proposition:

Proposition 4: Symbiotic business is a type of collaboration in which the strong integration among the engaged actors results in high requirements of trust, commitment, and reciprocity. Power is determined by organizational and relational sources, in which the difference of power among the partners have more influence on the relationship, in which companies with the most innovative solution can obtain more benefits from the collaboration.

4.5 DISCUSSIONS

Our case studies identified four main types of collaboration, mostly distinguished by trust, commitment and reciprocity elements of the SET, as shown in Figure 4.4. On the one hand, in collaborations with an underlying ecosystem-as-structure logic (ADNER, 2016), i.e. *Enhanced* and *Symbiotic businesses*, *trust* becomes an important mechanism for an open exchange of resources and information in joint activities required to create the focal value proposition, encouraging higher degrees of *commitment* by the partners. Oppositely, in the case of an underlying ecosystem-as-affiliation logic (*Expanded* and *Platform*), the main goal is to increase the dynamics of value creation and capture by combining synergic resources (ADNER, 2016), possibly without joint activities. In these cases, *trust* mechanisms are not essentially required. The difference between the two types of value creation focus is represented by the resource in consideration for the collaboration. In *Expanded* and *Platform*, the resource is more generalized, in which the data or platform provider will provide a *value in exchange*, in which later the partner will use it for their solutions. This demands a lower degree of *commitment* of the partners, not engaging in joint-activities. However, even though the value creation in the *Platform business* has a *value in exchange* dynamic, the value capture also has a *value in use* dynamic, as the platform needs the external actors to implement their solutions to become more valuable and attractive. Oppositely, in the *Enhanced business*, the value creation has a *value in use* dynamic, in which buyer and supplier work together to materialize the focal value proposition. However, the value capture has a *value in exchange* dynamic, as the supplier will provide access to its resource through negotiation and doesn't require its use by the buyer to capture revenues (CHESBROUGH; LETTL; RITTER, 2018). Lastly, the value creation and capture in the *Symbiotic business* have a *value in use* dynamic, as all actors jointly

create the focal value proposition, and all are dependent on each other for the value capture, even though each actor can have different levels of dependence. On the other hand, reciprocity will be higher when the collaboration has similarities of interests (*Platform* and *Symbiotic*), oppositely to the case of differences of interests (*Expanded* and *Enhanced*).

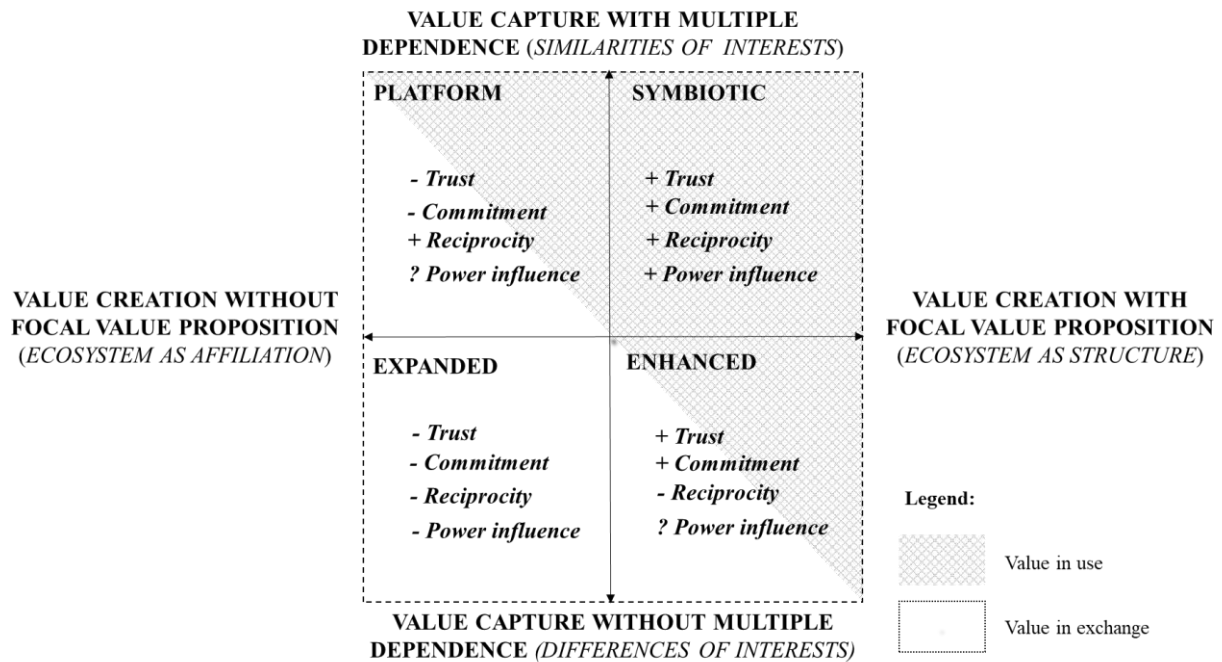


Figure 4.4 Conceptual framework to define the peculiarities of the four inter-firm collaboration types for digital servitization

Once the *power* of a company is determined by several factors (KÄHKÖNEN; VIROLAINEN, 2011), the *power* dynamics are not so clearly distinguished among the types of collaboration. In the *Symbiotic business*, the collaboration has a stronger integration of the partners, from operations to the management level. In this case, many *power* sources are considered, within both organizational and relational level. In addition, this collaboration type has a predominantly *value in use* dynamic for value creation and capture, which considers a more subjective perspective of the exchanges. Thus, in *Symbiotic business*, the collaboration is more susceptible of the *power* influence of one partner over the other, in which the partner with increased *power* has a dominator role, enforcing the adaptation of other actors to integrate into their digital architecture (KAMALALDIN *et al.*, 2021). Oppositely, the *Expanded business*, which has a weaker integration, considers factors mostly within relational level, the customer information obtained from the digital servitized solution and shared between the companies (KÄHKÖNEN; VIROLAINEN, 2011). Thus, this type of collaboration is less influenced by the difference of *power* among the actors, especially considering the value in exchange dynamic of value

creation and capture, with a more objective perspective of the exchanges. In between, *Enhanced business* might have a strong dependence of a specific resource of the partner, which can be counterbalanced by developing increased *trust* mechanisms in the relationship, also building a long-term *commitment* with the partner (FINNE; TURUNEN; ELORANTA, 2015). In this case, the actors follow a strategy based in complementarity for collaborations with higher joint activities and more requirements of open access to the partners' resources. With lower joint activities and limited resources and information sharing, the partners will follow a protector strategy, without mutual business openness (KAMALALDIN *et al.*, 2021). In the *Platform business*, the *power* will be dependent of the dynamics of the platform. In closed platforms, the integrated companies will be more influenced by the platform provider, as the case of Apple with its Homekit platform solution. The companies willing to offer smart product-based digital services must adapt to Apple's licensing regulations. In this case, product firms offer digital services to the customer through the platform, increasing Apple's centrality and expected power. In open platforms, the *power* will be balanced due to the increase of number of alternatives (FINNE; TURUNEN; ELORANTA, 2015). It is the case of IndustrialCo, in which the platform provider follows an orchestrator strategy, establishing an open architecture and encouraging cooperation among ecosystem actors. This brings new possibilities of value creation, which might lead to an increase of reciprocity among them (ADNER, 2016; KAMALALDIN *et al.*, 2021).

4.6 CONCLUSIONS

Our findings show how companies collaborate digital servitization regarding the elements for inter-firm social exchanges, taking into account the business structure and capabilities of the actors. The results of this research have both theoretical and practical implications as described next.

4.6.1 THEORETICAL CONTRIBUTIONS

By identifying elements that distinguish differences between the types of collaboration, we propose a framework for collaboration in digital servitization, considering different configurations in terms of value creation and value capture for each type. We offer advances in literature gaps on collaboration in digital servitization. Many authors have highlighted collaboration as an important strategy for this context, but, as pointed out by Kohtamäki *et al.*, (2019), further studies are necessary. The current literature on digital servitization and Smart

PSS usually takes the perspective of the firm or ecosystem (KOHTAMÄKI *et al.*, 2019; SKLYAR, A. *et al.*, 2019a). The ecosystem approach is important for this subject, as our findings and other research suggest increased levels of future engagement by companies in digital environments (BHARADWAJ *et al.*, 2013). However, it is also important to understand the dynamics of exchange and the relationships within these ecosystems. Our study provided new insights in this direction, showing how the interaction between the firms occurs within each type, by using a SET perspective for the first time in a digital servitization context. Thus, we extended the current literature of inter-firm relationships and business model innovation, especially the work of Pathak *et al.*, (2014), Gebauer *et al.* (2013), and Kamalaldin *et al.* (2021) in a digital servitization context. We also extended the findings of Saccani *et al.*, (2014) about buyer-supplier relationships in servitization, but in the context of digital servitization. Thus, as the main contribution of this expansion, we provide a taxonomy of four main business models in the digital servitization ecosystem approach and explain their inter-firm collaboration patterns that support such approaches using the social exchange theory to enlighten these patterns. As a result, scholars can find in this paper theoretical evidences of different models of ecosystems' arrangements, which can help to understand the complexity behind the ecosystem activities for digital servitization.

4.6.2 PRACTICAL IMPLICATIONS

Our results also offer practical implications for practitioners. The digital servitization phenomena, as already highlighted by studies, brings companies to work within collaborative ecosystems to gather the required resources, capabilities, and information for the operationalization of the company's business model. Our findings provide evidence on the elements that practitioners need to develop in the ecosystem's inter-firm collaboration when adopting a specific digital servitization business model. For instance, we showed that when the company follows a *Symbiotic business*, practitioners will have to reinforce the mutual trust due to the bilateral dependence for value creation and capture in a context where their partners can become also competitors in the market. We showed that in such a business the establishment of a power structure and a sense of reciprocity is also a key aspect to make this collaboration successful. We provide also similar insights for the other three configurations, showing what is relevant in each of them to manage the ecosystem. Thus, managers can understand how they can obtain more benefits by collaborating with other companies through Smart PSSs and their relational implications. Such understanding of the relational implications can support the

companies to evaluate the maintaining of their existing relationships, if whether they make further investments in relational assets or not, and to identify new business strategies with companies with complementary resources that might not even require these investments. Therefore, we provide initial evidence of how product firms can engage in the digital servitization process with new business opportunities through collaboration.

4.6.3 LIMITATIONS AND FUTURE STUDIES

We analyzed the current dynamic of our proposed typology and categorized them using the SET, choosing one case study in order to develop an in-depth analysis. However, this limits the generalization of our findings. Thus, we suggest further cases studies to corroborate or not our propositions. Moreover, we did not consider how companies arrived at the configurations and their transition and transformation. Future studies could consider the dynamic aspects of collaborations to capture such effects. In addition, we only considered supply chain relationships in the ecosystem. Previous studies on digital ecosystems have shown that other external direct and indirect actors play a key role in expanding digital capabilities (e.g., Kahle et al., 2020). Therefore, future studies can assess how other stakeholders can support these four types of collaboration. Moreover, we only analyzed single digital servitization business models in each company. We know that companies can adopt simultaneously different business approaches and several ecosystem configurations can coexist. A single analysis helps to understand better the underlying patterns, but future research would be required to investigate the complexity of managing different coexisting business types in the same ecosystem.

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APPENDIX A - INTERVIEW GUIDELINE

- 1) Could you tell me about your role in _____?
 - a. What is your position and how many years in the company and in the current unit are you working?
 - b. How many projects of product development have you participated? How many are you working now?
- 2) Do you have offerings composed by products and services?
 - a. Can you provide a description of the offering _____?
 - b. What is the product?
 - c. What services do you offer with the product (including digital applications)?
- 3) Are you having external support for development and/or delivery of this offering?
 - a. What kind of companies are engaged and what are their competencies?
 - b. How did you choose these companies? What factors made you chose them?
 - c. Do you have a contractual agreement with them? Is it included a follow up agreement for after the implementation?
- 4) How is the relationship with each company (the most important ones for the collaboration)?
 - a. What are the outcomes with the collaboration?
 - b. What is the value reward for the partner company?
 - i. Which dimension is more important?
 1. Cost-reduction for the development of the offering?
 2. Time compression: to reduce time to market?
 3. Innovation: to improve the product functionalities
 4. Access to new buyers/suppliers?
 5. Competency development?
 - ii. Based on the previous dimensions, how important is the supplier to the expected value?
 - iii. Do you expect an increased dependence of this supplier?
 - iv. Is there available different suppliers for this expected value?
 - v. How costly it would be to exit this relationship?
 - vi. What would be the expected value from the suppliers` perspective? (e.g. better price/increased volume orders, expected growth of the buyer`s business, innovation, access to new buyers, competency development)
 - c. Is it necessary trust for this relationship?
 - i. How would you address trust in the relationship?
 - ii. How is the partner`s loyalty? Is it important for you?
 - iii. How is the partner`s support for your needs?
 - iv. How is the partners` integrity?
 1. Does the partner has consistent beliefs with yours?
 2. Do you believe the partners` benefits are divided equally with your benefits?
 3. How do you consider if the partner is reliable?
 - d. Other elements:
 - i. What is the reciprocity with each actor?
 - ii. Is it expected to have a long term commitment?
 - iii. Is there a difference of power between the companies?

5 FINAL RESULTS AND DISCUSSIONS

This section synthesizes the results of Chapters 2, 3, and 4, establishing links among them. Firstly, Chapters 2 and 3 explain the role of inter-firm data integration in digital servitization. Secondly, these results relate inter-firm data integration to the social elements of inter-firm relationships and the collaborative configurations of Chapter 4.

5.1 THE ROLE OF INTER-FIRM DATA INTEGRATION IN DIGITAL SERVICIZATION

Figure 5.1 synthesizes the findings of Chapters 2 and 3. Chapter 2 shows the effect of technological turbulence on innovation performance of digital servitization, presenting a positive association. As expected, product firms in contexts with higher rates of technology change tend to bring more innovation in their solutions than companies with lower rates of technology change. However, the innovation performance construct also considers the entry into new markets, indicating that technological turbulence also incentivizes product firms to expand their markets. In this sense, a possible reason for not finding a significant association between market turbulence and innovation performance is that by addressing markets with greater changes in customer preferences, the product firms are unable to efficiently use resources in exploring new markets, even with the aid of Smart PSSs. Moreover, the associations of market and technological turbulence were affected by digitalization barriers. The success of developing Smart PSSs in industries with technological turbulence is associated with the presence of reliable internet infrastructure for data exchange. Thus, to benefit from digital servitization in this context, product firms must invest to guarantee their solutions' connectivity. In addition, despite the great advancements coming with the advent of digital technologies, the rise of cybersecurity threats has also been shown to negatively affect customer preferences, preventing the product firms from better exploring Smart PSSs in market turbulence contexts.

Amid the environmental conditions concerning market changes and technology adoption, Chapter 2 evidenced inter-firm data integration positively moderating Smart PSSs for increased innovation performance, but with restrictions. Firstly, both customer and supplier data integration support product firms to address market changes in the development of Smart PSSs. The customer data integration enables an understanding of their expectations and needs with Smart PSSs, while the

supplier data integration supports the product firms' operations to deliver the solutions. Unexpectedly, only customer data integration positively moderates Smart PSSs in technological turbulence. The results show that such integration is required to develop new solutions, but stronger integration with the customers can prevent product firms from seizing opportunities with new customers in other markets.

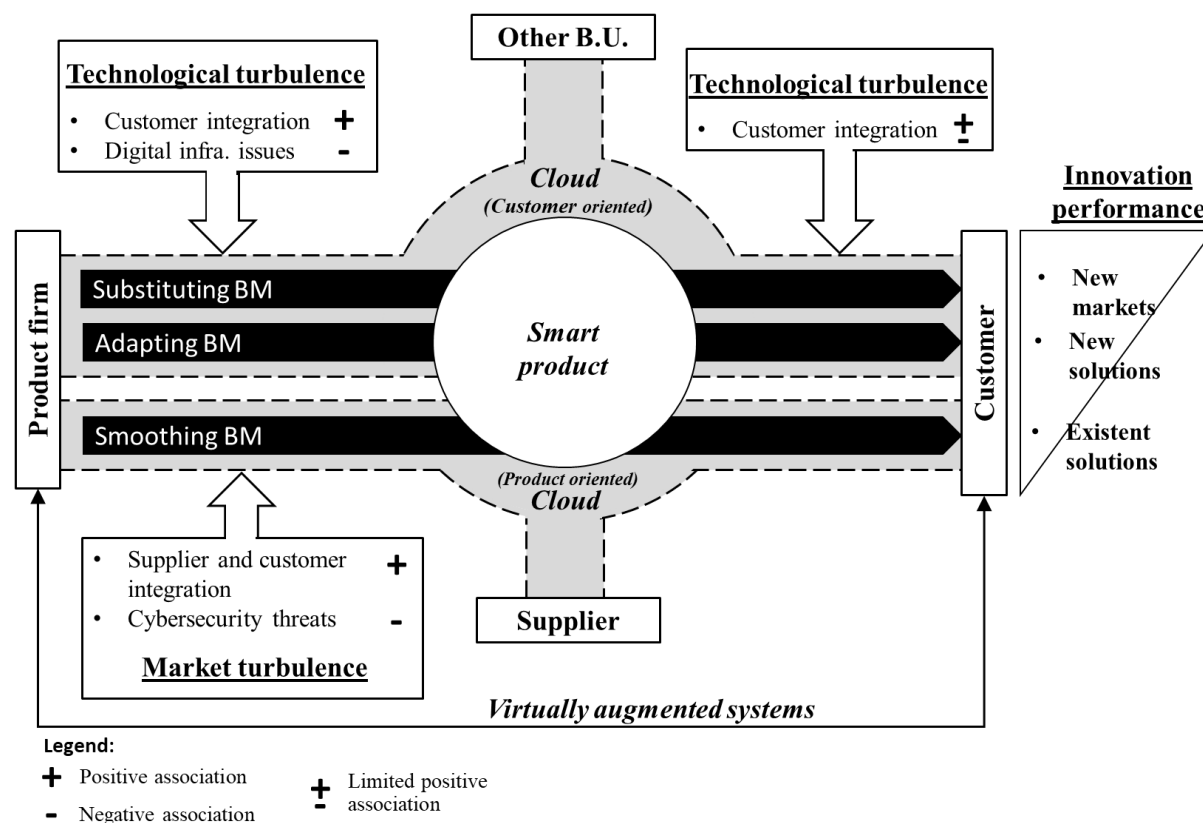


Figure 5.1 Summarized results on the role of inter-firm data integration in digital servitization.

The results of Chapter 3 complement the understanding of inter-firm data integration. The findings suggest that cloud systems provide such integration connected with smart products. The supplier data integration supports smoothing services in Smart PSSs, as the continuous monitoring of product conditions with suppliers allows more responsive maintenance and repair services. Meanwhile, the results indicate that only customer data integration supports adapting and substituting services in Smart PSSs. These two service orientations of PSS business models have a higher degree of innovation than smoothing services. Adapting services allow the customization of the offered solutions while substituting services consists of a radical innovation of product

business models, in which the customers only pay for the solution as they use it. In this sense, there is a match between the results in Chapter 2 and 3, as the offering of basic services benefit from supplier data integration, while the most innovative solutions in digital servitization demand customer data integration. However, the results in Chapter 2 show the existence of an optimal level of customer data integration that allows product firms to seize new market opportunities. In addition, Chapter 3 brings the role of other business units of the same product organization. The results indicate a centralized provision of digital services through cloud systems (customer-oriented) by these business units but integrated with the product firms.

5.2 INTER-FIRM DATA INTEGRATION AND SOCIAL ELEMENTS OF COLLABORATION

Chapter 4 approaches inter-firm collaboration from a relational perspective, describing the social elements of different collaborative configurations in digital servitization. More specifically, this chapter illustrates the relational implications in terms of trust, commitment, reciprocity, and power of the joint activities and resource interdependence for the development of Smart PSSs. Overall, the digital servitization literature has focused on the role of data integration with external partners (FREIJE; DE LA CALLE; UGARTE, 2021; SHAH *et al.*, 2020; SKLYAR *et al.*, 2019), not exploring the effect of data integration in relationships in digital servitization, or how social norms affect data integration.. Thus, the association between data integration and social elements is two-fold, as follows.

Trust is a social element frequently addressed by the literature in digital contexts (MORA-MONGE *et al.*, 2019; TRONVOLL *et al.*, 2020). As trust represents the openness of one company to the other, transparent information sharing based on data integration supports the development of trustworthy relationships. The results corroborate the literature indicating that a certain degree of trust is expected in sharing data with external actors (MORA-MONGE *et al.*, 2019). The negative effect of cybersecurity threats in contexts with market turbulence suggests that product firms should invest in cybersecurity mechanisms to guarantee the protection of personal data and ensure trust in customer relationships. The cybersecurity issues is a growing concern that can affect all industries (TRONVOLL *et al.*, 2020). In addition, interviewees in Chapter 4 also suggest the importance of first creating trustworthy relationships to exchange important data and information.

The data integration is also associated with the commitment between partners. An important barrier to developing long-term commitment relationships is the costs of relational assets, which can be reduced using ICTs for information sharing among companies. The literature acknowledges ICTS as efficient tools for communication and knowledge transfer (CUI *et al.*, 2022). In addition, the data integration allows performance indicators that can provide insights regarding the benefits of the relationship. For example, through the same mechanism Hertz provides ads of their rental solutions for KLM's customers (DELOITTE, 2014), Hertz can identify how much the use of KLM channel increases their customer reach performance in comparison to other channels. The company can choose between keeping the link with KLM or investing in other channels to reach potential customers. Furthermore, as described in Chapter 3, the knowledge transfer can be powered by virtually augmented systems, which even support the remote sharing of tacit knowledge.

Data integration brings advantages for reciprocity in collaborative relationships. Firstly, transparent information sharing by data integration also supports more reciprocal exchanges. Through data integration, partners are aware, and possibly in real-time, of their inter-linked routines, operations, and exchanges. Secondly, the Expanded business described in Chapter 4 shows new partnerships based on data sharing. As also shown by Deloitte (2014), data integration provides new opportunities for reciprocal relationships, not demanding high investments in relational assets. The mere exchange of data provides a win-win relationship, in which the data provider obtains a new source of revenue while the partner uses data for business improvement. This is in line with Danese (2007), which suggests that in some types of collaboration, data exchange suffices to achieve partners' goals in the relationship.

Lastly, unlike Mora-Monge *et al.* (2019), Chapter 4 shows data integration affecting power dynamics. The Expanded business describes ElectricCo, a product firm, obtaining a new revenue source through data exchange. However, the main goal of this strategy is to increase its power in the supply chain. The interviewees mentioned a lack of bargaining power by the company due to its upstream position in the supply chain, not directly accessing the end customers. In this case, the unbalanced power dynamics of the supply chain leads to a strategy to improve the bargaining power of the product firm through data exchange. Through digital services in the offered smart products, the company provides a direct link with this customer and is able to collect useful data for different actors in the ecosystem, which can become dependent on these data to improve their

business. These findings are aligned with Opresnik and Taisch (2015), which suggest data as the future key resource for competitive advantage in digital servitization.

5.3 DATA INTEGRATION IN COLLABORATIVE NETWORKS

Chapter 4 describes four collaborative configuration types of networks in digital servitization - the Expanded, Enhanced, Platform, and Symbiotic business - and their relational implications through social elements. Following the rationale of the previous section, data integration also affects these configurations.

In Chapter 4, the case study of Expanded business is centered on a collaboration based on data exchange, allowing many opportunities for new collaborations without the need for relational assets. Besides the insurance service provider that benefits from the exchanged data, the product firm can also share data with other product firms and service providers. For example, an important trend in sustainable initiatives is the development of smart grids and connected electricity networks with energy-efficient systems to reduce energy consumption (RYMASZEWSKA; HELO; GUNASEKARAN, 2017). The data collected from switchboards can support this purpose and include energy efficiency systems providers in the ecosystem. However, the data dependence can alter this configuration's relational implications. This new collaboration can demand stronger trust mechanisms to guarantee the safety of data exchange. If the data dependence is high, these companies must be more committed to each other and invest in relational assets. Similarly, this configuration can alter the reciprocity and power by unbalancing the interdependence dynamics of the partners.

The Enhanced business shows a traditional supply chain arrangement, in which the digital technology supplier supports the development of a new solution for the product firm and remains to collaborate in a long-term commitment through data sharing. The results of Chapters 2 and 3 show supplier data integration positively moderating the development of Smart PSSs, but mostly in providing more basic services. These findings are aligned with the literature, suggesting the role of supplier data integration in product firms' operations (ARDOLINO *et al.*, 2017; SHAH *et al.*, 2020c). However, the case study suggests a supplier engagement in some cases in developing

innovative solutions not represented in Chapters 2 and 3. Thus, more studies are required to fully understand the conditions of supplier integration in developing Smart PSSs.

The Platform business is also centered on systems integration with external actors. The IndustrialCo case study in Chapter 4 shows a cloud platform that enables product firms to develop digital services, complementing the value of their solutions. This case study corroborates the findings of Chapter 2, which shows that cloud systems greatly support the development of different servitized business models. Pirola *et al.* (2020) suggest that this type of arrangement through digital platforms is an important trend in industries. The results of Chapter 4 show such an approach improving the value of other solutions of the company, the development of new solutions through digital services from the platform, and the access to a new market of digital solutions, which creates new revenue sources for the company.

Lastly, the Symbiotic business shows collaboration with increased dependence of the engaged actors. The Symbiotic business also benefits from data integration. Joint ventures like Car2go can be represented by the integration with other business units of Chapter 3, as the development of a dedicated business unit centralizes the substituting services of Daimler, the product firm (SUAZO, 2021). These innovative business models greatly depend on data-processing activities, which can be supported by integration with other companies. The Apple and Nike case corroborate this finding, in which the sensors of Nike shoes integrate data with Apple's systems in phones, tablets, and smartwatches (BELAL; SHIRAHADA; KOSAKA, 2013). Thus, data integration supports such collaborative development of an innovative business model.

5.4 FINAL MODEL

Figure 5.2 summarizes the findings of Chapters 2, 3, and 4 in a framework.

As shown in Figure 5.1, the left side of the framework (Figure 5.2) illustrates the role of data integration through cloud systems of product firms with other business units, suppliers, and customers, according to the aimed innovation outcomes with Smart PSSs – addition revenues or cost reduction in existing solutions, new solutions, and new markets.

As no significant association was found between market turbulence and innovation performance in Chapter 2, such effect was only considered in the lowest degree of innovation performance, namely the development of existing solutions from the current portfolio of product firms. It is important to highlight that market turbulence can affect the other levels of innovation performance. However, the findings cannot confirm this effect in these contexts. Thus, in market turbulence, the data integration with suppliers and customers supports the development of Smart PSSs. As the strategic goal of the product firm increases the expected innovation outcomes, the importance of supplier data integration decreases, as the findings suggest their role in supporting operations to develop Smart PSSs mostly on developing existing solutions. Unlike supplier integration, the importance of customer data integration increases when the objective is to develop new solutions. However, as stated in Chapter 2, such integration is limited if the company's strategic goal is to access new markets. Chapter 3 shows an in-depth representation of data integration in servitized business models, also considering the role of other business units of the same product organization. For all three types of servitized business models considered, the integration with business units is significant, which centralizes the provision of digital services of Smart PSSs. As Chapter 2 considers only suppliers and customers, the effect of environmental factors or the degree of integration according to the aimed innovation outcomes were not considered with business units. In addition, from Chapter 3, the framework shows the provision of smoothing services with supplier data integration and the provision of adapting and substituting services with customer data integration. Lastly, when data integration through cloud systems is not possible, the product firm can remotely exchange information and knowledge on the customer's site through virtually augmented systems.

The right side of Figure 5.2 shows the inter-firm collaboration types according to the innovation degree of the developed solutions. Chapter 4 shows the four types of collaboration according to the value creation joint activities and value capture interdependence. More specifically, the model suggests collaboration types according to the value creation with or without a focal value proposition, following an ecosystem as structure and ecosystem as affiliation approach, respectively. The model also considers the existence of multiple dependence to capture value from the developed solutions. In each innovation degree, suitable collaboration types are proposed considering this goal.

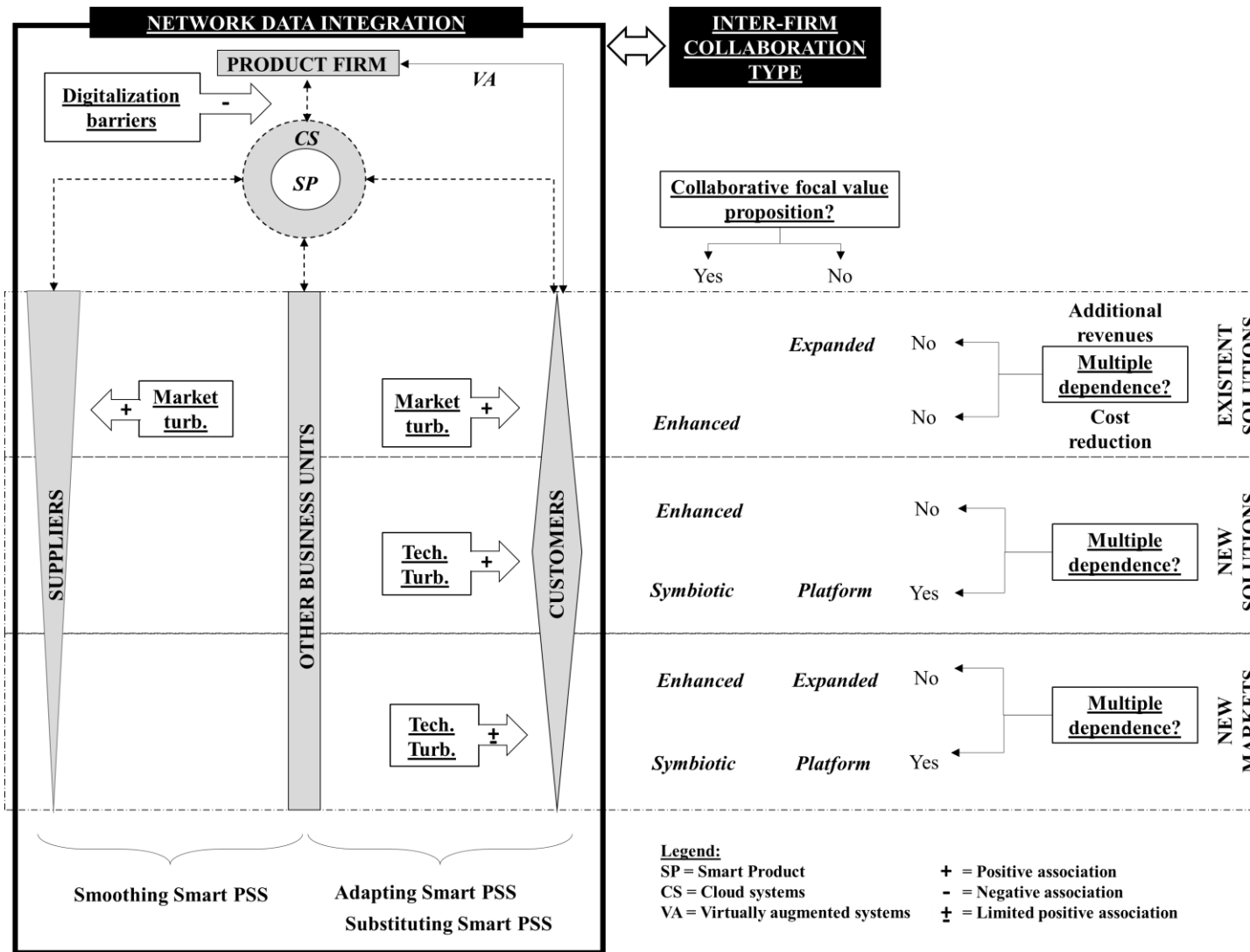


Figure 5.2 Final model proposition of Inter-firm collaboration and network data integration in digital servitization

Lastly, network data integration and inter-firm collaboration are interrelated. The former illustrates which actors must be integrated through data and how such integration changes according to the environmental factors, servitized business model, and innovation degree. The latter proposes collaborative configurations according to the innovation degree, value creation and capture dynamics, and social elements. While network data integration considers specific types of actors, inter-firm collaboration only considers the type of configuration. As shown in Chapter 4, the configuration types differ in their configurations, in which different possibilities of integrated actors are possible, according to the desired outcome of the product firm.

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6 CONCLUSIONS

This chapter presents the thesis' theoretical and practical contributions and the opportunities for future research. The thesis explores inter-firm collaboration and network data integration in digital servitization under environmental conditions, technical requirements, and relational implications. The results suggest the importance of integrating the customer through data in Smart PSSs for improved innovation performance of product firms in digital servitization. Such integration appears to have an optimal level to address the current customer needs and explore new markets. Meanwhile, supplier data integration appears to be more relevant in optimizing the operations concerning Smart PSSs development and delivery. In some cases, the mere exchange of data suffices to achieve partners' goals in the collaboration. In other cases, there is a requirement for joint activities which demand the development of relational assets. Overall, the findings suggest that inter-firm collaboration and network data integration positively support the digital servitization process, either by improving operational routines or the innovation activities of product firms, as shown in the proposed model of Figure 5.2. These findings bring advancements in the digital servitization literature.

6.1 THEORETICAL CONTRIBUTIONS

As mentioned in section 1.2, several research gaps in digital servitization concern the collaboration with other actors and the role of digital technologies. Firstly, our study considers a multi-actor perspective, as Raddats *et al.* (2019) suggested. As proposed by the authors, we also addressed the synergies of different networked actors in digital servitization, in which Chapters 2 and 3 have a data integration approach, while Chapter 4 considers a relational approach. We also bring advancements in the research gaps concerning the service delivery processes and the role of digital technologies by considering a multi-channel digital service delivery system in Chapter 3. We also addressed some research directions proposed by Kohtamäki *et al.* (2019). In Chapter 2, we showed how product firms can obtain a competitive advantage in digital servitization in terms of increased innovation performance. In Chapter 4, we approach value creation and capture dynamics in collaborative configurations for Smart PSSs. In addition, by considering the environmental factors and inter-firm data integration in Chapter 2 and the relational implications in Chapter 4, we studied the interactions of Smart PSSs providers with their ecosystems and the external determinants of the innovation path of digital servitization, as proposed by Pirola *et al.* (2020). Lastly, the developed model in Chapter

5 approaches business models, value co-creation and capture, and performance improvement, the digital servitization-related themes, in the holistic approach suggested by Paschou *et al.* (2020).

Regarding network data integration in digital servitization, the thesis provides advancements in the role of data for competitive advantage in digital servitization, as conceptually suggested by Opresnik and Taisch (2015). In Chapters 2 and 3, we bring confirmatory studies of the data contribution for innovation performance and business models centered on Smart PSSs. In Chapter 4, we show how product firms can profit from the collected data of Smart PSSs. In addition, we bring clarifications concerning the integration with different actors in service ecosystems. We advanced the results of Shah *et al.* (2020), identifying the business models in servitization that call for integration with suppliers and customers. We corroborate the results of Wang, Gao, and Wei (2021) by showing an optimal level of customer integration for improved innovation performance. Moreover, Chapter 3 shows the integration with other business units, which centralizes the provision of digital services of Smart PSSs, as suggested by Sklyar *et al.* (2019).

The inter-firm collaboration approach in Chapter 4 brings important contributions to the literature on digital servitization. Based on a proposed taxonomy of four collaborative business models in digital servitization, we showed the relational implications of collaboration, as proposed by Bastl *et al.* (2012), but in a digital context. The consideration of digital environments in servitization is important, considering the growing use of digital technologies and data-processing activities in the process. Furthermore, the results in Chapter 4 extend the literature on inter-firm relationships and business model innovation, especially the work of Kamalaldin *et al.* (2020) and Gebauer, Paiola, and Sacconi (2013). In this sense, our work supports understanding the complexity behind ecosystems in digital servitization, especially considering the relationship between network data integration and inter-firm collaboration in the proposed model of Chapter 5.

6.2 PRACTICAL CONTRIBUTIONS

The proposed model in Chapter 5 describes important factors determining relational advantage in digital servitization. This model clarifies some environmental conditions, technical requirements, and relational implications of collaborating with external actors with Smart PSSs. Based on these results, product firms can understand how to engage external actors in

their business models according to the industry structure in which they operate, the desired innovation outcome according to their strategy, technological resources required for Smart PSSs, and the relational implications for developing these solutions with the external actors. In this sense, the results can guide managers in decision-making activities for the success of the digital servitization process.

The model provides a general landscape of collaborating with external actors in digital servitization. Chapters 2, 3, and 4 provide specific practical contributions to this subject. In Chapter 2, product firms can understand two digitalization barriers affecting the innovation performance of their solutions and how market and technological turbulence change this performance. Chapter 3 clarifies how different digital channels can support the development of different servitized business models, considering the data integration with external actors. In Chapter 4, the case studies support an understanding of how collaborating with external actors brings opportunities for new revenues, solutions development, and access to new markets, clarifying the social elements required in each proposed collaboration type. In addition, some results call for the attention of practitioners, such as the existence of an optimal level of customer data integration to seize new market opportunities. In this context, the thesis support product firms to avoid the so-called servitization paradox.

6.3 OPPORTUNITIES FOR FUTURE RESEARCH

The thesis provides opportunities for further studies in digital servitization. Firstly, we adopted inter-firm collaboration and networks units of analysis by focusing on interactions and exchanges of collaborating actors. These units are suitable for the objectives of this research, but more studies must be complemented from an ecosystem perspective. As stated by Kohtamäki *et al.* (2019), research on digital servitization must consider an ecosystem perspective, as the business opportunities transcend the supply chain level, including many other types of companies and institutions that can affect the servitization process. One example is identifying internet infrastructure issues as a barrier to the digital servitization process. As mentioned in Chapter 2, developing a reliable internet infrastructure can depend on different actors, including governmental institutions. Thus, the ecosystem approach can support companies in understanding the digital servitization journey.

One limitation of the articles is that they were mostly based on the machine industry. Although digital servitization is a growing trend, not all industrial companies have implemented or

started implementing the process. As the machine industry is prone to adopt a digital servitization strategy due to its technical degree, we chose this sector. However, other sectors must be considered to understand different patterns of inter-firm collaboration, network data integration, environmental factors, and innovation performance in digital servitization. These findings can complement the proposed model in Chapter 5.

Another limitation is that collaboration has a static approach in this research. In other words, we analyzed existing collaborative relationships' integration degree and relational implications. Future research could perform longitudinal studies to analyze collaboration from a dynamic perspective. In this approach, studies can identify factors in forming collaborative relationships. In addition, studies could analyze data integration in different stages of the product lifecycle, identifying which moments call for more integration and how digital technologies can support it. Lastly, the studies on inter-firm collaboration and data integration in digital servitization could use a dynamic capabilities approach, analyzing the optimal development of resources and capabilities with external actors to seize new opportunities for innovation performance and competitive advantage.

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Résumé étendu

La concurrence croissante dans les entreprises manufacturières a conduit ces dernières à innover leurs produits et processus, ainsi que leurs business modèles. Les entreprises ont intégré des services à leurs offres de produits et offrent dorénavant des systèmes produit-service (SPS) pour mieux répondre aux besoins de leurs clients et améliorer leurs activités, obtenant ainsi un avantage concurrentiel plus important (KOHTAMÄKI *et al.*, 2019). Le processus d'intégration des services aux produits s'appelle servicisation. La servicisation est devenue un objet de recherche en raison de son potentiel pour créer de nouvelles sources de revenus, mieux répondre aux besoins des clients, proposer des offres innovantes et fidéliser les clients (BAINES *et al.*, 2017). Les avantages obtenus dépendront du type de services que les entreprises fourniront à leurs clients. Des services plus avancés offrent davantage de possibilités d'améliorer les performances en matière d'innovation ainsi que la croissance des entreprises (CHEN *et al.*, 2021). Les chercheurs dans le domaine de la servicisation ont mené des études approfondies sur le potentiel apporté d'avantages concurrentiels grâce à des solutions innovantes, en accédant également à de nouveaux marchés. Cependant, la principale lacune de la recherche reste la manière dont les entreprises manufacturières peuvent exploiter efficacement ce processus de servicisation (BAINES *et al.*, 2017). La servicisation implique le développement de nouvelles capacités opérationnelles et dynamiques qui dépassent l'expertise des entreprises manufacturières, exigeant généralement des investissements élevés qui n'apportent pas nécessairement les rendements attendus (GEBAUER; FLEISCH; FRIEDLI, 2005). De plus, ces capacités sont fortement liées aux facteurs de contingence de la servicisation et notamment aux turbulences environnementales tels que les turbulences du marché et technologiques (FRANK *et al.*, 2022). Pour surmonter ce problème, les entreprises manufacturières peuvent suivre deux stratégies de collaboration complémentaires: la mise en œuvre de technologies digitales pour intégrer les données en réseau et le développement de capacités pour la collaboration interentreprises (ARDOLINO *et al.*, 2020; SHAH *et al.*, 2020c).

La convergence entre digitalisation et servicisation fait référence à la notion de servicisation digitale. Dans ce contexte, la digitalisation a permis une plus grande intégration des entreprises manufacturières avec des acteurs externes importants pour créer de la valeur (SHAH *et al.*, 2020c; SKLYAR *et al.*, 2019d). Dans les environnements digitaux, ces acteurs échangent des données en temps réel améliorant différentes activités de la supply chain. L'intégration des données dans les réseaux de collaboration offre de nouvelles possibilités pour les SPS plus

avancés (SHAH *et al.*, 2020c). Les services digitaux étant centrés sur les données diffusées par différentes sources, l'intégration des données interentreprises implique que les acteurs collaborent étroitement dans des réseaux connectés.

La seconde stratégie poursuivie par les entreprises manufacturières pour soutenir le processus de servicisation est la collaboration interentreprises. La collaboration entre les acteurs a été considérée comme une stratégie clef pour le processus de transformation vers la servicisation (GEBAUER; PAIOLA; SACCANI, 2013). Les capacités liées aux services et leur déploiement avec les produits nécessitent une structure coûteuse. Afin d'atteindre les clients et de répondre à leurs besoins, l'ensemble de la supply chain doit être plus intégrée pour exécuter et évaluer les services (SHAH *et al.*, 2020). Ainsi, dans un contexte servicisé, le fabricant est plus susceptible de collaborer avec d'autres acteurs, tels que les fournisseurs et les prestataires de services, formant différentes configurations collaboratives de réseaux pour développer et fournir des SPS intelligents.

La collaboration inter-entreprises et l'intégration des réseaux sont des sources clés d'innovation, améliorant la création de valeur et générant des opportunités pour tous les acteurs engagés afin de capturer plus de valeur avec les solutions (KOHTAMÄKI *et al.*, 2019; SHAH *et al.*, 2020c). Ce contexte conduit à renforcer les liens opérationnels du réseau de l'entreprise manufacturière et modifie les arrangements structurels des relations, dans lesquels les normes relationnelles complètent les contrats par des mécanismes informels de gouvernance, comme la confiance. Ces mécanismes sont nécessaires pour encourager l'échange ouvert d'informations requis entre les acteurs et pour inciter leur participation au réseau. Ainsi, la collaboration interentreprises peut créer des ressources et des capacités supérieures fondées sur les connaissances liées à la prestation de services, améliorant ainsi les performances commerciales et d'innovation des entreprises manufacturières dans le processus de servicisation (BASTL *et al.*, 2012 ; GEBAUER ; PAIOLA ; SACCANI, 2013).

Considérant les rôles majeurs de la collaboration dans les réseaux, de l'intégration des données et des facteurs environnementaux dans la servicisation digitale, la présente thèse aborde **les trois questions de recherche** suivantes :

- (i) *Les systèmes produits-services (SPS) intelligents aident-ils les entreprises manufacturières à améliorer leur performance innovation dans un contexte de*

turbulences environnementales ? Quel est le rôle de l'intégration des données interentreprises et des obstacles à la digitalisation dans la servicisation digitale ?

- (ii) *Dans quelle mesure les différents acteurs de l'écosystème des services contribuent-ils, par l'intégration des données avec les entreprises manufacturières engagées dans la servicisation digitale, à soutenir la prestation de services digitales multicanaux dans les business modèles des SPS intelligents ?*
- (iii) *Comment les collaborations interentreprises peuvent-elles être configurées pour offrir des SPS intelligents ?*

Cette thèse se situe à la croisée des deux domaines disciplinaires que sont le management de la supply chain et le génie industriel. Le thème de cette recherche concerne la collaboration interentreprises dans le processus de servicisation digitale.

L'objectif général de cette thèse est de développer un modèle qui explique le rôle de la collaboration avec les principaux acteurs des écosystèmes de services, à savoir les différentes unités d'une entreprise manufacturière, les fournisseurs et les clients, dans une démarche de servicisation digitale. Ce modèle vise à clarifier les facteurs environnementaux, les exigences technologiques et les implications relationnelles de la collaboration avec les acteurs externes par les technologies digitales dans un contexte de servicisation digitale. L'objectif est d'explorer les deux aspects de la collaboration dans les environnements digitaux. Le premier aspect de la collaboration est lié à l'intégration des données avec des acteurs externes qui est nécessaire pour créer un système d'échange d'informations efficace et répondre aux besoins du marché (CHEN *et al.*, 2021; OPRESNIK; TAISCH, 2015). Cette perspective considère le rôle des technologies digitales et de l'intégration des réseaux pour soutenir leur mise en œuvre dans les SPS intelligents. Le second aspect de la collaboration est représenté par des activités conjointes avec partage de ressources, échange de capacités et développement d'actifs relationnels (DYER; SINGH; HESTERLY, 2018). Cette perspective est fondée sur les éléments de la théorie de l'échange social, à savoir la confiance, l'engagement, la réciprocité et le pouvoir, identifiés par la littérature sur le management de la supply chain comme des déterminants de la relation entre les acteurs (WU *et al.*, 2004). En outre, ce modèle prend en compte le principal moteur du processus de servicisation digitale, l'augmentation de la performance d'innovation des entreprises manufacturières pour obtenir un avantage concurrentiel sur leurs marchés (COREYNEN *et al.*, 2020).

Dans ce contexte, pour comprendre comment les entreprises manufacturières collaborent avec d'autres entreprises en servicisation digitale et répondre aux trois questions de recherche, cette thèse a été construite par articles. Chaque article répond à une question de recherche et la combinaison des résultats des trois articles permet de proposer un modèle conceptuel qui répond à l'objectif générale de la thèse. Dans cette optique, nous avons adopté une méthode mixte de recherche en mobilisant des enquêtes et des études de cas afin de saisir la richesse du phénomène étudié, et d'en offrir une image complète pour construire notre modèle (VENKATESH; BROWN; BALA, 2013). Dans les articles 1 et 2, la recherche est explicative, avec un objectif de confirmer les hypothèses proposées sur les phénomènes étudiés. L'article 3, consiste en une recherche exploratoire, visant à comprendre les mécanismes et les déterminants de la collaboration inter-firmes. La description de chacun des trois articles ainsi que les méthodes adoptées sont décrites ci-après.

Article 1 (Chapitre 2) - "*Innovation performance of digital servitization in environmental turbulence: the role of inter-firm data integration and digitalization barriers*". L'article vise à comprendre le rôle des turbulences environnementales (turbulences du marché et technologiques), de l'intégration des données interentreprises et des barrières à la digitalisation dans la performance d'innovation de la servicisation digitale. Nous confirmons les hypothèses de la littérature en utilisant un modèle de régression linéaire avec des effets de médiation (SPS intelligents) et de modération (turbulences environnementale, intégration de données interentreprises, et barrières à la digitalisation) sur un échantillon de 102 fabricants d'équipements au Brésil. Les résultats montrent un effet positif des turbulences technologiques sur la performance de l'innovation à travers les SPS intelligents, dans lesquels l'intégration des données clients soutient son développement. Cependant, les résultats indiquent une relation en forme de U inversé entre cette intégration et la performance d'innovation. L'intégration des données des fournisseurs modère positivement le développement de SPS intelligents dans un contexte de turbulences du marché, mais aucun résultat significatif sur la performance d'innovation n'a été trouvé dans ce contexte. L'article montre les implications de l'intégration des données de réseau pour comprendre les turbulences environnementales et améliorer la performance d'innovation dans la servicisation digitale.

Article 2 (Chapitre 3) - "*Multichannel digital service delivery and service ecosystems: the role of data integration within Smart Product-Service Systems*". Cet article examine la provision de services intégrés dans les SPS intelligents et mobilisant des technologies digitales

qui nécessitent des données externes provenant de réseaux collaboratifs. Il vise à comprendre comment la provision de services par trois canaux digitaux spécifiques (produits intelligents, cloud system et systèmes virtuellement augmentés) peut être soutenue par l'intégration de données provenant de trois acteurs clés dans les écosystèmes de services (autres unités commerciales, fournisseurs et clients) afin de fournir différents business modèles de SPS intelligents. La recherche est fondée sur une enquête auprès de 92 fabricants d'une association brésilienne de constructeurs d'équipements. Les résultats fournissent trois cadres pour décrire comment les données en temps réel du réseau et les technologies digitales sont combinées dans chaque business modèle de SPS intelligents.

Article 3 (chapitre 4) - "Inter-firm collaboration for Smart Product-Service Systems: a Social Exchange Theory perspective". Considérant la collaboration interentreprises comme une stratégie importante pour la création et la capture de valeur dans la servicisation digitale, cet article vise à définir les principales configurations de la collaboration interentreprises pour les SPS intelligents. Sur la base de la revue de la littérature, quatre configurations de collaboration sont proposées. Ensuite, une étude de cas multiples est appliquée pour chaque type de collaboration. Ces cas ont été analysés selon les éléments de la *Social Exchange Theory* (SET) : confiance, engagement, réciprocité et pouvoir. Les résultats montrent que le type de configuration pour la collaboration varie en fonction du niveau d'innovation recherché dans l'offre SPS intelligent. Pour chaque type de collaboration, différents arrangements des éléments SET ont été trouvés. L'étude fournit une analyse approfondie de la collaboration interentreprises pour les SPS intelligents.

La Figure 5.2 résume les résultats des chapitres 2, 3 et 4 dans un modèle. Le côté gauche du modèle illustre le rôle de l'intégration des données par les *cloud systems* des entreprises manufacturières avec leurs différentes unités commerciales, les fournisseurs et les clients, en fonction du degré d'innovation des SPS intelligents développés.

Comme aucune association significative n'a été trouvée entre les turbulences du marché et la performance d'innovation dans le chapitre 2, cet effet n'a été considéré dans un cas où le niveau d'innovation du SPS est faible, à savoir le développement de solutions existantes à partir du portefeuille actuel de produits et services des entreprises manufacturières. Ainsi, en cas de turbulence du marché, l'intégration des données avec les fournisseurs et les clients soutient le développement de SPS intelligents. Lorsque la stratégie de l'entreprise manufacturière a pour

objectif d'augmenter ses résultats en matière d'innovation, l'importance de l'intégration des données des fournisseurs diminue, car les résultats suggèrent que leur rôle dans le soutien des opérations de développement de SPS intelligents repose principalement sur le développement de solutions existantes. Contrairement à l'intégration des données fournisseurs, l'importance de l'intégration des données clients augmente lorsque l'objectif est de développer de nouvelles solutions. Cependant, comme indiqué au chapitre 2, cette intégration est limitée si l'objectif stratégique de l'entreprise est d'accéder à de nouveaux marchés. Le chapitre 3 présente une représentation approfondie de l'intégration des données dans les modèles d'entreprise servicisée, en considérant également le rôle des différentes unités commerciales de l'entreprise manufacturières. Pour les trois types de business modèles servitisés considérés, l'intégration avec les unités commerciales est significative, ce qui centralise la provision de services digitaux des SPS intelligents. En outre, à partir du chapitre 3, le cadre montre la provision de *smoothing services* avec l'intégration des données des fournisseurs et la fourniture de *adapting* et *substituting services* avec l'intégration des données des clients. Enfin, lorsque l'intégration des données par le *cloud systems* n'est pas possible, l'entreprise manufacturière peut échanger à distance des informations et des connaissances sur le site du client grâce à des systèmes virtuellement augmentés.

La partie droite de la figure 5.2 montre les types de collaboration interentreprises en fonction du degré d'innovation des solutions développées. Quatre types de collaboration sont proposés, en fonction des activités conjointes de création de valeur et d'interdépendance dans la capture de valeur. Plus précisément, le modèle suggère des types de collaboration en fonction de la création de valeur avec ou sans proposition de valeur émanant de l'entreprise focale, selon une approche d'écosystème respectivement en tant que structure ou affiliation. Le modèle considère également l'existence d'une dépendance multiple pour capturer la valeur des solutions développées. Dans chaque degré d'innovation, des types de collaboration appropriés sont proposés en tenant compte de cet objectif.

Enfin, l'intégration des données du réseau et la collaboration interentreprises sont liées. La première illustre quels acteurs doivent être intégrés par les données et comment cette intégration change en fonction des facteurs environnementaux, du modèle d'entreprise en servicisation et du degré d'innovation. La seconde propose des configurations de collaboration en fonction du degré d'innovation, de la dynamique de création et de capture de la valeur, et des éléments sociaux. Alors que l'intégration de données en réseau prend en compte des types

d'acteurs spécifiques, la collaboration interentreprises ne prend en compte que le type de configuration. Les types de configuration diffèrent dans leurs configurations, dans lesquelles différentes possibilités d'acteurs intégrés sont possibles, en fonction du résultat souhaité par la firme productrice.

En conclusion, la thèse explore la collaboration interentreprise et l'intégration des données de réseau dans la servicisation digitale en fonction des conditions environnementales, des exigences techniques et des implications relationnelles. Les résultats suggèrent l'importance d'intégrer le client à travers les données dans les SPS intelligents pour améliorer la performance d'innovation des entreprises manufacturières dans la servicisation digitale. Une telle intégration semble avoir un niveau optimal pour répondre aux besoins actuels des clients et explorer de nouveaux marchés. En revanche, l'intégration des données des fournisseurs semble être plus pertinente pour optimiser les opérations concernant le développement et la livraison des SPS intelligents. Dans certains cas, le simple échange de données suffit pour atteindre les objectifs des partenaires dans la collaboration. Dans d'autres cas, il est nécessaire de mener des activités conjointes qui exigent le développement d'actifs relationnels. Dans l'ensemble, les résultats suggèrent que la collaboration interentreprises et l'intégration des données en réseau soutiennent positivement le processus de servicisation digitale en améliorant soit les routines opérationnelles, soit les activités d'innovation des entreprises manufacturières, comme le montre le modèle proposé dans la figure 5.2. Les résultats répondent à plusieurs lacunes de la recherche sur la servicisation digitale liées à la collaboration avec d'autres acteurs et au rôle des technologies digitales.

La thèse offre des opportunités pour des études plus approfondies dans la servicisation digitale. Dans un premier temps, nous avons adopté comme unité d'analyse de la collaboration inter-firmes les interactions et les échanges entre acteurs. Cette unité est adaptée aux objectifs de cette recherche, mais d'autres études sont à mener dans une perspective écosystémique. Comme indiqué par Kohtamäki et al. (2019), la recherche sur la servicisation digitale doit tenir compte d'une perspective écosystémique, car les opportunités commerciales transcendent le niveau supply chain, Comme mentionné au chapitre 2, par exemple le développement d'une infrastructure Internet fiable peut dépendre de différents acteurs, y compris les institutions gouvernementales.

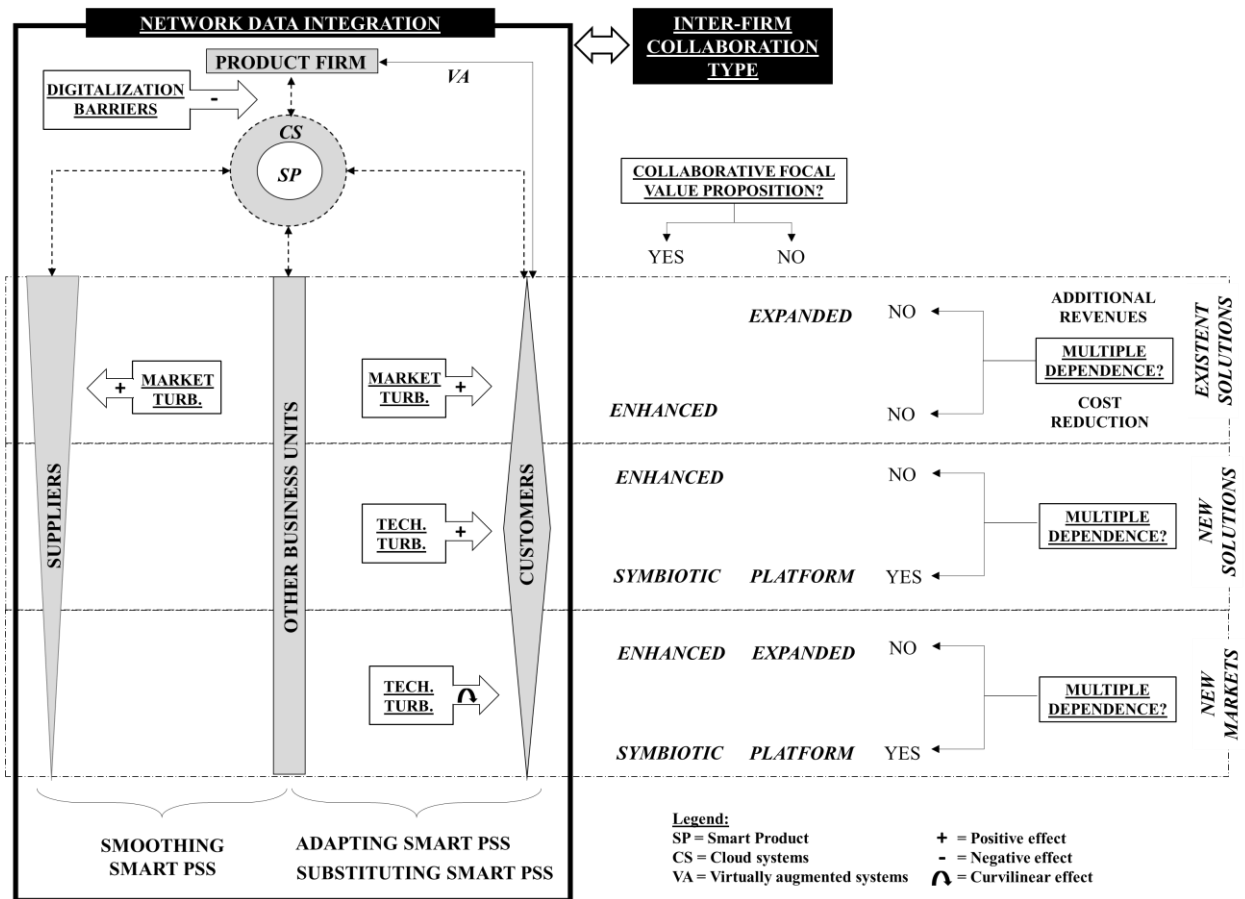


Figure 5.2. Proposition de modèle final de collaboration interentreprises et d'intégration des données de réseau dans la servicisation digitale.

Une des limites de nos enquêtes est qu'elles étaient principalement dans l'industrie des machines. L'industrie des machines a adopté une stratégie de servicisation digitale en raison de son niveau technique, et c'est la raison du choix de ce secteur dans notre recherche. L'étude d'autres secteurs constitue un axe de recherche futur pour compléter le modèle proposé au chapitre 5.

Une autre limite est que la collaboration a une approche statique dans cette recherche. En d'autres termes, nous avons analysé le degré d'intégration et les implications relationnelles des relations collaboratives existantes. Les recherches futures pourraient réaliser des études longitudinales pour analyser la collaboration dans une perspective dynamique. Dans cette approche, les études peuvent identifier les facteurs dans la formation de relations de collaboration. De plus, des études pourraient analyser l'intégration des données à différentes étapes du cycle de vie du produit, en identifiant les moments qui nécessitent une plus grande intégration et comment les technologies numériques peuvent la soutenir. Enfin, les études sur

la collaboration inter-firmes et l'intégration des données dans la servicisation digitale pourraient utiliser une approche dynamique des capacités, analysant le développement optimal des ressources et des capacités avec des acteurs externes pour saisir de nouvelles opportunités de performance d'innovation et d'avantage concurrentiel.

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