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The Interplay of Product Modularity, Service Types, and Servitization Depth on Firm Performance: A Moderated Mediation Model

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Abstract

The servitization literature has explored the role that product modularity plays in supporting service design and delivery. Importantly, product modularity has the potential to aid manufacturers in providing customized solutions on a larger scale, thereby strengthening firm performance. However, despite the prospective benefits of product modularity, manufacturers also need considerable servitization depth, which comprises service orientation, resources, and delivery systems, to provide services in a cost-effective manner. Taking this into account, the study both theoretically articulates and empirically tests relationships among product modularity, servitization depth, service types, and firm performance, employing a moderated mediation model. Using survey data collected from 204 manufacturers in the UK and German, the findings indicate that product modularity exerts a positive influence on firm performance, with servitization depth acting as a mediating factor. The mediation effect of servitization depth on the correlation between product modularity and firm performance was found to fluctuate based on the service types offered by the manufacturer. This study adds to the existing literature on servitization and the role of product modularity and servitization depth in achieving superior firm performance.

Keywords: servitization, servitization depth, firm performance, product modularity, service types

1. Introduction

In the context of contemporary business models, industrial services have emerged as a potent mechanism for generating stable revenue streams, along with increased profit margins (Worm et al. 2017; Eggert et al. 2014). Consequently, there has been a paradigm shift in the business strategy of manufacturing firms (Rabetino, Kohtamäki, and Gebauer 2017), transitioning from purely product-centric models towards the provision of integrated product-service offerings – a transformation frequently termed as 'servitization' (Baines et al. 2017; Kastalli and Looy 2013; Vandermerwe and Rada 1988). Servitization involves a transformation in service orientation, delivery systems, and resource base, with the aim of creating, delivering, and capturing more value from services (Sjödin, Parida, Jovanovic, et al. 2020; Kowalkowski et al. 2017; Vendrell-Herrero et al. 2017). Yet, literature indicates that manufacturing firms expanding their service businesses frequently encounter heightened complexity in both design and delivery of their product-service solutions (Kowalkowski et al. 2015; Davies and Brady 2000; Paiola et al. 2013). For instance, literature recognizes that servitization is a relational process *with* the customer, which results in the development of many ad-hoc and one-off customized solutions (Davies and Brady 2000; Davies et al. 2021). This situation limits the ability of manufacturers to fully utilize their well-established manufacturing capabilities, given the difficulties they encounter when trying to scale customized solutions (Rajala et al. 2019; Davies et al. 2021; Johnson et al. 2021). Therefore, in response to the challenges associated with scaling customized solutions (i.e., customized physical products for different customer needs), scholarly investigations have started to delve into the potential role of product modularity as a facilitator of these customized solutions (Salonen, Rajala, and Virtanen 2018; Johnson et al. 2021).

A manufacturing firm's core capability is characterized by their proficiency in mobilizing bundles of resources to support manufacturing processes that are product-centric (Sousa and da Silveira 2017). Consequently, product modularity is viewed as an intrinsic component of this manufacturing capability (Davies et al. 2022; Davies et al. 2021). The positive effect of product modularity on the performance of servitized firms has been suggested by several studies (Rajala et al. 2019; Johnson et al. 2021). First, the benefits of product modularity for firms include increased efficiency, improved flexibility, and reduced differentiation costs (Kohtamäki, Einola, and Rabetino 2020; Rajala et al. 2019). For instance, Mikkola (2006) highlights that product modularity enables the efficient development of customized solutions by re-combining basic components and utilizing standardized interfaces. Second, product modularity can also provide new opportunities for service provision, as evidenced by several studies (Salonen, Rajala, and Virtanen 2018; Brax et al. 2017; Liu, Zhao, and Lee 2021). Hsuan et al. (2021) note that maritime firms utilizing modular vessels can effectually maintain critical systems, including propulsion, navigation, and communication, through interchangeability. This is particularly applicable within the swiftly transforming landscape of technological advancements, where modularity serves as a pivotal enabler for the continued development and customization of digital services (Zangiacomi et al. 2020; Thomson et al. 2023). Consequently, product modularity ought to enable the delivery of a diverse array of service types, encompassing base, intermediate, and advanced services (Hsuan, Jovanovic, and Clemente 2021; Baines et al. 2017), leading to improved firm performance (Kastalli, Looy, and Neely 2013; Wang, Lai, and Shou 2018). Nonetheless, additional research is necessitated to substantiate this association through the examination of fundamental aspects of product modularity such as functional binding, interface standardization, and decomposability (Vickery et al. 2016), in the context of the expansion of the service business.

As manufacturers transition from a product-oriented to a service-oriented business model, they start to oversee operations formerly undertaken by the customer, imposing the development of novel service capabilities (Jovanovic et al. 2019; Raddats et al. 2017; Marcon et al. 2022; Story et al. 2017). Ayala, Gerstlberger, and Frank (2019) suggest that "servitization depth" includes three key dimensions: service orientation, resource base, and delivery system. Moreover, the degree to which manufacturers need to develop servitization depth varies as a function of the service types they offer such as base, intermediate, and advanced services (Baines and Lightfoot 2013). Correspondingly, Sousa and da Silveira (2017), Jovanovic et al. (2019) and Marcon et al. (2022) posit that as manufacturers progress along the product-service continuum, advancing from base to more sophisticated services, there is an increasing dependence on their capacity to customize solutions and their servitization depth. Therefore, the economic gain from a servitization strategy cannot be solely attributed to product modularity, as it also requires a robust framework of both manufacturing and service capabilities (Sousa and da Silveira 2017; Jovanovic et al. 2019; Marcon et al. 2022). The influence of product modularity on manufacturers who have embarked on the servitization journey is likely to fluctuate based on the service types they offer and their corresponding servitization depth. These variables can potentially have diverse implications for firm performance. Yet, the empirical investigation into the interplay of these factors remains limited. This indicates a pronounced need for additional research focusing on the role of product modularity, service types, and servitization depth in optimizing the firm performance (Salonen, Rajala, and Virtanen 2018; Salonen, Rajala, and Virtanen 2018; Johnson et al. 2021).

To address the knowledge gap, this study aims to examine the relationships between product modularity, servitization depth, service types, and firm performance in the context of manufacturing firms in the United Kingdom (UK) and Germany. A sample of 204 manufacturing firms was analyzed using Structural Equations Modelling (SEM) as proposed by Hayes (2013), which enables the integration of moderation and mediation analyses into a single model (Holland, Shore, and Cortina 2017). The findings reveal that (1) product modularity has a positive impact on firm performance, (2) servitization depth positively mediates the relationship between product modularity and firm performance, and (3) the moderating effect of service types offered by the manufacturer on the mediation of servitization depth was observed. The results suggest that while base and advanced services are more dependent on servitization depth, intermediate services are more reliant on product modularity. This study adds to the existing servitization literature by providing a deeper understanding of the antecedents of firm performance (Kastalli and Looy 2013; Li et al. 2023; Wang, Lai, and Shou 2018; Bustinza et al. 2019), with a focus on product architectures (Rajala et al. 2019; P. Davies et al. 2021; Johnson et al. 2021; Hsuan, Jovanovic, and Clemente 2021), service portfolio development (Paiola et al. 2013; Alghisi and Saccani 2015) and servitization depth (Ayala, Gerstlberger, and Frank 2019).

This paper is organized into five sections. In the first section, we provide a theoretical foundation for our study along with the associated hypotheses development. In the second section, we describe the methodology adopted in our research, including the sample selection and data analysis techniques. The third section presents the results of our study, which are discussed and contextualized within the existing servitization literature in the fourth section. The final section concludes by highlighting the managerial implications and limitations of the research and suggests avenues for future inquiry.

2. Theoretical background

2.1. Product modularity and firm performance

The concept of modularity in product development refers to the capability to construct complex systems from smaller, independently designed components that interact and integrate seamlessly with each other (Baldwin and Clark 2000; Baldwin 2023). This approach to product architecture leverages standardized interfaces and interchangeable components, which can be updated, altered, or reconfigured into more sophisticated systems with reduced dependence on managerial coordination (Schilling 2000). The modularity literature has evolved from a primary focus on the modularity of products to a broader view of the applicability of modularity in servitization literature (Frandsen 2017; Salonen, Rajala, and Virtanen 2018; Brax and Visintin 2017).

In the context of servitization, product modularity presents several advantages, such as enabling the design and delivery of complex, customized solutions in an industrially efficient manner, thereby enhancing flexibility, reducing the costs of differentiation, and promoting sustained competitiveness in dynamic environments (Rajala et al. 2019; Wang and Zhang 2020). For instance, while the literature suggests that the development of one-of-a-kind industrial solutions can be prohibitively expensive (Davies, Brady, and Hobday 2006; Davies et al. 2022), product modularity may help firms to lower the cost of creating diverse solutions and attain economies of repetition by aggregating modular components (Brady, Davies, and Gann 2005; Davies and Brady 2000). In addition, successful firms tend to leverage the knowledge and experience gained from these complex solutions by streamlining them and standardizing various components (Kowalkowski et al. 2015). Consequently, product modularity enables manufacturing firms to create the prerequisites for repeatability and scalability (Kowalkowski et al. 2015). Additional benefits include the possibility for firms to specialize in component design, integration, or reconfiguration of modular component (Salonen, Rajala, and Virtanen 2018). By doing this, product modularity also enables firms to build portfolios of products (Eggert et al. 2011) that can be combined to offer customers a range of customized solutions efficiently (Johnson et al. 2021). Despite the potential benefits of product modularity within the servitization context (Salonen, Rajala, and Virtanen 2018), there is a noticeable gap in empirical literature that quantitatively links these two concepts, particularly in relation to firm performance (Davies et al. 2021; Rajala et al. 2019). Based on this review, we propose the following hypothesis:

Hypothesis 1*: In the context of servitization, product modularity is positively associated with enhanced firm performance.*

2.2. Product modularity, servitization depth, and firm performance

Whilst product modularity can be considered a manufacturing capability that supports customized solutions at scale, servitization also requires a large-scale transformation in service capabilities for manufacturing firms to progressively create, deliver, and capture increased service value (Jovanovic et al. 2019; Ayala, Gerstlberger, and Frank 2019; Marcon et al. 2022). Therefore, while product modularity may positively affect the firm performance as posited in H1, servitization success also hinges on the development of service orientation within the firm's staff and processes, coupled with the required service-centric delivery systems, and resource base for effective service provision (Ayala, Gerstlberger, and Frank 2019). Collectively these three areas are referred to as servitization depth in this paper.

Firstly, the performance of a servitized firm is influenced by its service orientation (Lenka et al. 2018). Service orientation is instrumental in facilitating the shift from a manufacturer's traditional product-centric orientation, characterized by an emphasis on efficiencies and standardization, towards a customer-centric model that necessitates incorporation of service characteristics - intangibility, inseparability, variability, perishability, and non-ownership (Bowen, Siehl, and Schneider 1989; Tuli, Kohli, and Bharadwaj 2007). Service orientation is frequently conceptualized concerning the breadth of service types provided, the diversity of the customer base served, and the degree of active customer involvement in service delivery (Homburg, Hoyer, and Fassnacht 2002). In this context, Mathieu (2001), Oliva and Kallenberg (2003), and Eggert et al. (2014) made a distinction between two categories of services, namely, Services Supporting the Clients' Action (SSC) and Services Supporting the Supplier's Product (SSP). The former category prioritizes the client's needs and requirements, while the latter category focuses on the supplier's product and its performance. In a servitization strategy, SSC are typically prioritized as they contribute significantly to competitive advantage and value creation (Eggert et al. 2014). However, SSCs demand a deep understanding of customer needs and operations (Raja et al. 2013; Kamalaldin et al. 2020) along with active customer involvement in service design and delivery (Sjödin, Parida, Jovanovic, et al. 2020). Therefore, service orientation demonstrates firm’s commitment to delivering services that meet customers' needs and expectations (Mathieu 2001). Overall, Homburg et al. (2002) argue that service orientation is a mindset and approach of a firm that prioritizes and integrates service offerings into its overall strategic orientation (Day 1994).

Secondly, in terms of enhancing firm performance through servitization, the development of an efficient delivery system and the configuration of a service-centric activity system are critical determinants (Kohtamäki et al. 2019; Visnjic, Neely, and Jovanovic 2018; Zott and Amit 2010). Studies suggest that creating a distinct service business unit with its own cost center is vital for promoting a service-oriented mindset and culture (Gebauer, Fleisch, and Friedli 2005). Yet, studies also underscore the challenges of managing the integration of product and service business units, as salient conflicts that may arise (Visnjic et al., 2021). Furthermore, distinct service delivery systems may be required for different service types (Adrodegari et al. 2017) such as in the case of advanced services (Visnjic et al. 2017; Bigdeli et al. 2018), with varying structures, partners, and levels of openness within a business model (Visnjic, Neely, and Jovanovic 2018; Chesbrough 2006). Hence, successful service delivery hinges not only on the efficient orchestration of internal activity systems, such as business units, but also on the effective management of accountable external service network partners such as distributors, suppliers, and technology partners (Hullova, Laczko, and Frishammar 2019; Parida et al. 2016). In the context of global service delivery, studies indicate that these delivery systems may possess increased complexity, requiring an efficient service network for successful service provision (Parida and Jovanovic 2022; Kowalkowski, Kindström, and Brehmer 2011; Aminoff and Hakanen 2018).

Finally, firm performance is contingent upon the possession of appropriate resources for servitization such as specialized service capabilities, as evidenced by multiple studies (cf. Jovanovic et al. 2019; Story et al. 2017; Ulaga and Reinartz 2011; Marcon et al. 2022). Building on the resource-based view of the firm (Barney, Wright, and Ketchen 2001), literature emphasizes the importance of developing both front-end and back-end service capabilities for the effective provision of services (Valtakoski and Witell 2018; Gebauer, Fleisch, and Friedli 2005). For instance, front-end service capabilities include responsiveness via specialized service sales force (Ulaga and Loveland 2014) and human capital (Rabetino, Kohtamäki, and Gebauer 2017), engaging with service partners and orchestrating service networks (Parida and Jovanovic 2022), positioning within service ecosystems (Kamalaldin et al. 2021), management of service customization (Sjödin, Parida, and Kohtamäki 2016), and service pricing management (Rapaccini 2015). On the other hand, back-end service capabilities include the adoption and use of digital technologies (Opresnik and Taisch 2015; Frank et al. 2019), agile and micro-service design methods (Qi et al. 2020; Thomson et al. 2023), standardizing service processes and developing service-centric KPIs (Jovanovic et al. 2019), and managing ongoing product-service tensions (Visnjic, Jovanovic, and Raisch 2022). Consequently, it is widely accepted that the procurement of resources, particularly in the form of service capabilities, is a fundamental for effectively penetrating the service market, which in turn, positively impacts firm performance (cf. Wang, Lai, and Shou 2018).

In sum, in addition to product modularity that supports scaling of customized solutions (Rajala et al. 2019), leveraging only manufacturing capabilities to deliver services is not sufficient to improve firm performance (Sousa and da Silveira 2017). In this context, the cultivation of servitization depth across three key dimensions - namely, service orientation, delivery systems, and resource base, is regarded as a complementary to manufacturing capabilities, specifically product modularity. Based on our review, we posit that these three dimensions, collectively seen as servitization depth, mediate the relationship between product modularity and firm performance. Based on this review, we offer the following hypothesis:

Hypothesis 2*: The impact of product modularity on firm performance is mediated by the servitization depth, considering its three dimensions - service orientation, delivery systems, and resource base.*

2.3. Service types

In addition to the mediating role of servitization depth, it is important to consider the service types offered by a firm (i.e., base, intermediate or advanced services) (Baines and Lightfoot 2013). The literature suggests that the success of various service types may necessitate differing levels of manufacturing and service capabilities (Story et al. 2017; Sousa and da Silveira 2017;

Jovanovic et al. 2019). Moreover, the level to which they need to develop service capabilities varies as a function of the service types provided by the firm. As an example, Sousa and da Silveira (2017) found that advanced services relied more heavily on service capabilities than manufacturing capabilities due to the increased customer orientation in the delivery of such services. Similarly, Jovanovic et al. (2019) noted that the maturation of service capabilities tends to align with the type of service being provided, sequentially progressing from base to intermediate, and ultimately to advanced services, often starting with the front-end service capabilities. Building upon this foundation, we are now extending this perspective to explore the interplay between product modularity, servitization depth, and the variety of service types provided by manufacturing firms.

First, base services are aimed at ensuring the operational efficiency of equipment (Wise and Baumgartner 1999; Raddats and Easingwood 2010). They encompass aspects such as spare parts supply and other standardized, transactional, product-oriented services (Lele 1986). As these services have minimal relation to how customers derive value from the product and the interaction with the provider remains transactional, the value generated primarily stems from product functionality (Kowalkowski and Ulaga 2017). In particular, base services do not mandate a deep understanding of the customer, but instead associate with manufacturing capabilities (Sousa and Silveira 2017), allowing them to remain the preferred supplier for standard aftermarket services (Ulaga and Reinartz 2011; Jovanovic, Engwall, and Jerbrant 2016). Within the scope of our study, product modularity could potentially boost the efficiency of base services, such as spare parts provision. This can be accomplished by capitalizing on economies of scale or scope during the design, reconfiguration, and remanufacturing stages of base services (Rabetino et al. 2018). Specifically, product modularity allows for more standardized, repeatable processes, which can lead to cost savings through large-scale production and varied application across different base services (Salonen, Rajala, and Virtanen 2018). Furthermore, product modularity may facilitate upgradability, efficient warranty support, and serviceability due to 'differential consumption' (Gershenson, Prasad, and Zhang 2003; Krikke, Blanc, and van de Velde 2004). However, research suggests that base services, while not directly impacting firm performance, serve as an essential prerequisite for the successful deployment of advanced services (Sousa and Silveira 2017). Regarding the sales of base services, achieving the necessary scale and geographic distribution hinges critically on the degree of servitization depth, especially with respect to the delivery system component (Parida and Jovanovic 2022). Based on this understanding, we hypothesize that:

Hypothesis 3a*: In the context of base services, it is proposed that firm performance resulting from servitization is more closely associated with product modularity than servitization depth.*

Second, intermediate services are characterized by their extended timeframe, which includes the support of products throughout their entire lifecycle to maximize operational efficiency, such as through scheduled maintenance and overhaul services to ensure optimal product performance (Baines and Lightfoot 2013; Visnjic, Neely, and Jovanovic 2018; Ulaga and Reinartz 2011). Next, intermediate services such as remote monitoring services are often associated with standardized hardware (e.g., Internet of Things sensors) and software components (Kapoor et al. 2021; Boehmer et al. 2020; Frank et al. 2019). These features can be particularly beneficial in scenarios such as data-driven fault analysis (Jovanovic, Sjödin, and Parida 2022) and may assist maintenance services as components at fault can be identified, isolated, and replaced with ease (Grubic 2018; Cenamor, Sjödin, and Parida 2017). Crucially, the standardization of both design and delivery of intermediate services denotes the uniformity of components (Salonen, Rajala, and Virtanen 2018) and allows reducing complexity and increasing overall efficiency (Kapoor et al. 2021). Yet, intermediate services also necessitate a certain degree of servitization depth to ensure the effective design and delivery. Studies argue that these services are frequently developed and delivered in cooperation with external partners (Bustinza et al. 2019; Alghisi and Saccani 2015), such as technology partners or service delivery partners (Jovanovic, Sjödin, and Parida 2022). For instance, to meet the needs of intermediate services customers, there is an increased need for field service, helpdesk support, operator training, and extended timeframe that requires accountability for service provision (Visnjic, Neely, and Jovanovic 2018). Therefore, intermediate services require an elevated level of servitization depth due to requirement for high responsiveness and proactiveness (Marcon et al. 2022; Holmström, Liotta, and Chaudhuri 2017), implementation of new service processes (Paiola et al. 2013), product lifecycle methodologies (Rabetino et al. 2015) and customer intimacy capabilities (Rabetino, Kohtamäki, and Gebauer 2017). Given this understanding, our proposed hypothesis for the role of intermediate services as a moderating factor is as follows:

Hypothesis 3b: *In the context of intermediate services, it is proposed that firm performance resulting from servitization is closely associated with both product modularity and servitization depth, with servitization depth playing an increasingly mediating role compared to base services.*

Finally, advanced services prioritize the provision of capability and outcome-based contracting (Visnjic et al. 2017; T. Baines et al. 2017). This focus aligns with a long-term, performance-oriented approach (Selviaridis and Wynstra 2015). Notably, these offerings are often recognized as the most complex within the servitization literature (Bigdeli et al. 2018). Advanced services are exemplified in models such as Royce's power-by-the-hour, Michelin's pay-per-kilometer, Xerox's pay-per-copy, and Electrolux's pay-per-wash (Gebauer et al. 2017). Advanced services are typically developed through a dyadic process that involves value creation and value capture between the provider and customer, encompassing the stages of value proposition definition, value provision design, and value-in-use delivery (Sjödin et al. 2020; Raddats et al. 2017). They are distinguished by a high level of customization to cater to individual customer needs (Davies et al. 2021; Sjödin, Parida, and Kohtamäki 2016) and require complex service capabilities for successful development and delivery (Story et al. 2017; Marcon et al. 2022; Jovanovic et al. 2019). Moreover, advanced services are also identified as customer solutions (Tuli, Kohli, and Bharadwaj 2007; Rabetino et al. 2018), combining products, services, and information, with the specific objective of addressing a customer's problem (Sawhney, Wolcott, and Arroniz 2006). Therefore, viewed through the lens of problem-solving, the value of advanced services manifests in their pivotal roles in addressing customer challenges, where servitization depth increases customer-centric performance outcomes (Zhang, Wei, and Gao 2023; Ye, Priem, and Alshwer 2012). On the other hand, studies report that most providers of advanced services keep modularization to a bare minimum (Kapoor et al. 2021), since advanced services are more associated with the integral product architectures and proprietary software solutions (Hsuan, Jovanovic, and Clemente 2021). Therefore, the success of advanced services is likely to hinge more on the servitization depth than directly on product modularity (Davies et al. 2021; Sousa and Silveira 2017). Building on this analysis, the proposed hypothesis for the role of advanced services as a moderating factor is:

Hypothesis 3c*: In the context of advanced services, it is proposed that firm performance resulting from servitization is more closely associated with servitization depth than product modularity, with servitization depth playing an increasingly mediating role compared to base and intermediate services.*

The research model is depicted in Figure 1. The subsequent section provides a comprehensive presentation of the methodology employed in this study.

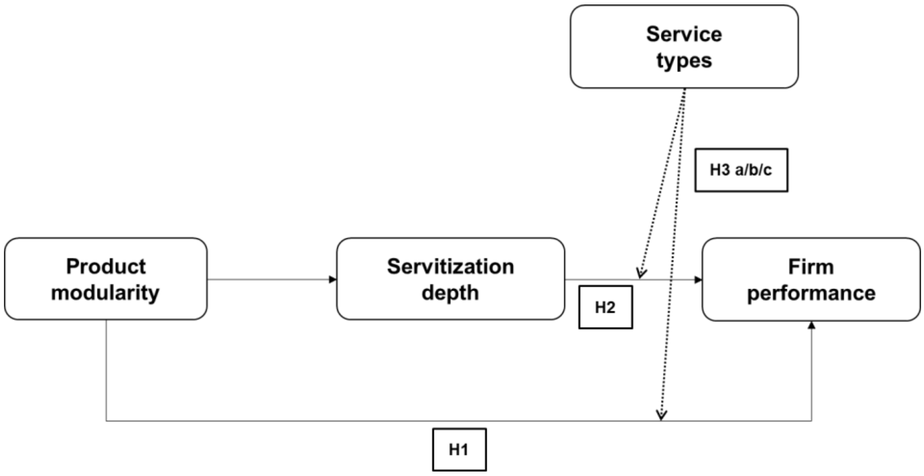

Figure 1. Research model

3. Methods

3.1. Data collection and sample

For this study, data were collected by Qualtrics on behalf of the research team. Qualtrics were provided with a set of exclusion criteria to ensure respondents met the requirements of our study. First, our study excluded any respondent that worked for a manufacturing company outside the UK or Germany. These two countries were selected as they are recognized as countries with leading manufacturing industries and have played a leading role in the servitization of manufacturing (Bustinza, Opazo-Basaez, and Tarba 2021; Vendrell-Herrero et al. 2017). Where a respondent selected a country that was not the UK or Germany, they were removed from the survey. Second, our study excluded companies with less than 100 employees in line with Kohtamäki et al. (2013), considering that micro and smaller enterprises are unlikely to offer manufacturing-based services. Third, the study excluded firms that did not have a Standard Industrial Classification (SIC) code between 10 and 39, which identifies firms within the industrial and manufacturing sectors (Visnjic, Wiengarten, and Neely 2016). Finally, responses from individuals who were below management level within the relevant service business unit of the manufacturer were excluded from the study in order to remain consistent with our model (Sousa and da Silveira 2017). Such respondents were directed to the end of the survey and excluded from the final dataset.

In the initial phase, a pilot study was conducted involving 25 samples to validate that the purpose of the questions would not be misconstrued. Subsequently, the questionnaire was disseminated, yielding a total of 248 responses. However, incomplete data was provided by 44 companies within the sample, which resulted in a final sample size of 204 manufacturing firms. This included 100 German firms and 104 UK firms. To determine variations among groups, a two group-mean comparison test was carried out on the two country subsamples. The test results did not provide any evidence to suggest a significant average performance difference between the groups $(t(df = 202) = 0.159; p > 0.05)$. Considering the population of manufacturing firms (N=16,692), with a confidence level of 95% (Z=1.96) and a margin of error of 5% (e=5%), and given p=0.2 and q=0.8, the minimum necessary sample size is 194 firms. The number of firms in the collected sample exceeds this minimum requirement. Regarding the variety of services provided by the manufacturers, the sample encompassed 21 firms exclusively offering base services, 54 providing intermediate services, and 129 firms delivering a range of advanced services.

3.2. Tests for non-response and common method bias

To assess the potential for non-response bias (NRB), a comparison was conducted between early and late respondents in relation to the independent, moderator, and dependent variables (Armstrong and Overton 1977). This established approach to NRB employs t-tests to verify if significant discrepancies exist between early and late respondents (Armstrong and Overton 1977). The analysis revealed no significant differences statistically between these two respondent groups, even at the 10% level ($p>0.1$). Employee count served as a control variable to evaluate the significance of NRB by comparing data from responding and non-responding firms as collected by the survey firm. Here too, no statistically meaningful disparities were detected between the two groups at the aforementioned level ($p>0.1$). These outcomes indicate that NRB does not pose a concern within our final sample.

The potential for common method bias (CMB) might present a challenge in this study, considering that the survey was completed by a single respondent from each firm (Podsakoff and Organ 1986). To mitigate issues related to CMB, the study design implemented a proximal separation between independent and dependent variables (Podsakoff, MacKenzie, and Podsakoff 2012b). A clear definition of each measure was provided in the survey to diminish the likelihood of 'systematic response tendencies' influencing responses, thereby aiding in the reduction of CMB (Podsakoff, MacKenzie, and Podsakoff 2012a). To ensure that respondents were familiar with the topics under study, we developed a pilot test that incorporated academics, industry experts, and firms belonging to the sample population (Forza 2002; MacKenzie and Podsakoff 2012). In an attempt to minimize CMB, the survey emphasized that "This survey seeks to reveal the complex interplay between product modularity, the level of service orientation, delivery systems and resource base, and firm performance." Furthermore, the inclusion of service types as a moderating variable assisted respondents to easily visualize the objective of the survey, therefore reducing the potential for CMB.

Finally, we employed a standard validity statistical procedure, the Unmeasured Latent Method Factor (ULMF), to assess CMB (Williams, Cote, and Buckley 1989). This procedure integrates a common method factor into the confirmatory factor analysis (CFA) model. Items are loaded onto both their corresponding latent variables and the newly introduced common method factor. The estimated model displays a suboptimal fit (CFI=0.732 and TLI = 0.629, below the threshold acceptance range of >0.900; and RMSEA = 0.096, outside the threshold acceptance range of 0.050 to 0.080), indicating that the common-method factor does not accurately account for the variance in the data. As a result, we can confidently state that all systemic sources of bias potentially impacting the relationships between variables are controlled (Podsakoff, MacKenzie, and Podsakoff 2012b).

3.3. Variables

Dependent variable: *Firm performance (FP)* is recognized as a reliable and consistent scale of measures that have been used in operations management research previously (Wang, Lai, and Shou 2018; Sila 2007; Zhou et al. 2020). A five-point Likert scale (1-strongly disagree to 5-strongly agree) is used to measure the extent to which respondents agree each dimension of firm performance grew faster than their competitors in the period three years post-adoption of a servitization strategy. This variable consists of five indicators that measure market share, profit, overall competitive position, return on assets, and successful introduction of new products and/or services. Scale's internal consistency is measured through the *Cronbach's alpha* ($\alpha = 0.733$), having *composite reliability* a measure of 0.746 and *average variance extracted* a measure 0.500. These results are all within the acceptable thresholds of 0.7, 0.7. and 0.5 respectively (Hair et al. 2010). We used Stata v.17 commands *condisc* and *avecr* to calculate convergent and discriminant validity (Mehmetoglu 2015).

Independent variable: *Product modularity (PM)* is a scale measured through 9 items included in a questionnaire using a 5-point Likert scale (1= Total disagreement, 5 = Total agreement) to assess perceived product modularity developed by (Vickery et al. 2016). Principal component analysis with Varimax rotation reports two dimensions of 4 items each, measuring *functionality* (functions can be directly added or deleted by adding or removing components, components have standardized interfaces, products can be into separate modules, and are easily reconfigured) and *variability* (products have interchangeable features and options, are designed to enable the swapping of components, are designed to accept a variety of other components, and are able to accept a wide range of complements). One of the items from the original scale (changes in components can be made without changing other components) was dropped because of low factor loading (below the 0.7 recommended threshold). The other eight items are statistically significant; factor loadings are above the recommended level of 0.4, individual reliabilities are higher than 0.6, with Total Variance Extracted of 57.367%. *Cronbach's alpha* for the *functionality* dimension was 0.702 while Cronbach's alpha for the *variability* dimension was 0.707, with values above the recommendable 0.7 threshold value. For composite reliability, measures were 0.714 for *functionality* and 0.716 for *variability*, with average variance extracted measures of 0.529 and 0.559, respectively.

Mediator and moderator variables: While there is a distinction between mediation and moderation (Karazsia and Berlin 2018), these concepts can be integrated (Hayes 2013; Preacher, Rucker, and Hayes 2007; Muller, Judd, and Yzerbyt 2005; Holland, Shore, and Cortina 2017). This integration can advance theory development, theory testing, and ultimately offer more thorough understandings of complex phenomena (Karazsia et al. 2014). We analyzed the mediation effect of *Servitization depth* and the moderation effect of *Service types*. The objective was to test if *Servitization depth* explains the relationship between *Product modularity* and *Firm performance*, and if *Service types* changed the relationship (i.e., varied as a function of the service types provided). *Servitization depth* is developed from validated measures adopted from Ayala et al. (2019). It is composed of three dimensions, namely, service orientation, resource base, and delivery system, which include a total of fourteen items. Linear prediction is used to operationalize this into a continuous variable, which is more useful when analyzing the mediation role.

Moderator variable: *Service types* variable adopts the three service types developed by Baines and Lightfoot (2013): Base (outcomes are based on product provision), Intermediate (outcomes focused on product condition), and Advanced services (outcomes focused on capability). Base services are assessed with three variables, including equipment provision, spare parts, and warranty services; intermediate with five variables including scheduled maintenance, helpdesk, training services, field services, and condition monitoring; and advanced service with three variables, support agreements, performance-based contracts, and advanced outsourcing/rental services. Table 1 provides a detailed descriptive statistical analysis and intercorrelations of four key variables: *Product modularity*, *Servitization depth*, *Firm performance*, and *Service types*. The reported Pearson correlation coefficients indicate significant positive associations between product modularity and servitization depth ($r = 0.672$, $p < 0.01$), and between product modularity and firm performance ($r = 0.550$, $p < 0.01$). In addition, a strong positive correlation was observed between servitization depth and firm performance ($r = 0.680$, $p < 0.01$). However, the associations of service types with the other variables were not statistically significant, demonstrating limited direct relationships. Appendix 1 contains the questionnaire distributed to respondents.

Table 1. Descriptive analysis and correlations between the variables

Variables	1	2	3	4
1. *Product modularity*	1			
2. *Servitization depth*	0.672*	1		
3. *Firm performance*	0.550*	0.680*	1	
4. *Service types*	0.094	0.095	-0.019	1
Mean	4.083	4.201	4.132	2.529
Standard deviation	0.662	0.647	0.578	0.676

Note: * p<0.01

4. Results

We tested the hypotheses through Structural Equations Modelling (SEM) using Stata v.17. and following Maximum Likelihood estimation (Hayes, Montoya, and Rockwood 2017). Results show a positive relationship between *Product modularity* and *Firm performance* $\beta_{Mod\rightarrow Perf} = 0.361$ ($t = 2.821$; $p < 0.01$), supporting Hypothesis 1 (see Table 2). Three sets of indicators reflect a satisfactory goodness of fit for the model: absolute measures Chi-squared likelihood ($CMIN = 65.634$; $p = 0.386$) or Root mean square error ($RMSEA = 0.069$), inside the acceptance range from 0.050 to 0.080; incremental measures Compared fit index ($CFI = 0.986$) or Tucker-Lewis index ($TLI = 0.983$), acceptance range >0.900; and parsimony measure Normed Chi-square ($CMINDF = 2.441$), inside the acceptance range from 1 to 5 (Acock 2013; Hair et al. 2010). To test the mediation effect of *Servitization depth* on the relationship between *Product modularity* and *Firm performance*, firstly, we corroborated that *Product modularity* had a positive effect on *Servitization depth* ($\beta_{Mod\rightarrow SerP} = 0.756$ ($t = 3.977$; $p < 0.01$), and that *Servitization depth* had a positive effect on *Firm Performance* ($\beta_{ServP\rightarrow Perf} = 0.456$ ($t = 3.231$; $p < 0.01$).

Secondly, we calculated the total effect that *Product modularity* had on *Firm performance* when *Servitization depth* is included in the model. The direct effect is the parameter for H1 reported in the previous paragraph ($Direct\ effect = \beta_{Mod\rightarrow Perf} = 0.361$) plus the indirect effect due to *Servitization depth*, that is, the product between the parameters $\beta_{Mod\rightarrow SerP}$ and $\beta_{ServP\rightarrow Perf}$ ($Indirect\ effect = \beta_{Mod\rightarrow SerP}\ x\ \beta_{ServP\rightarrow Perf} = 0.756\ x\ 0{,}456 = 0.345$). Therefore, the $Total\ effect = 0.361 + 0.345 = 0.706$, equal the direct and indirect effect, meaning that the impact of *Product modularity* on *Firm performance* is due to both effects, with *Servitization depth* almost responsible for half of the impact ($0.345/\ 0.706 = 48.867\%$ of the effect is due to *Servitization depth*). Finally, we performed bootstrapping (Hayes and

Scharkow 2013), resampling equal to 1,000, to analyze the mediation role of *Servitization depth*. Bootstrap standard error does not cross zero at a 95% confidence level, meaning that *Servitization depth* is a mediator on the relationship between *Product modularity* and *Firm performance,* $Bootstrap\ standard\ error = 0.0233\ (between\ 0.0131\ and\ 0.684)$, thus supporting Hypothesis 2.

Upon investigating the path *Product modularity→Servitization depth→Firm performance*, we assessed potential variations depending on the service types: Base service, Intermediate service, and Advanced service. This classification followed the classification by Baines and Lightfoot (2013), where offerings containing multiple service types are grouped under the more complex category. The analysis revealed intriguing results. For Base services ($Total\ effect = 0.141 + 0.548 = 0.689$), *Servitization depth* appears to hold a dominant influence on the effect of *Product modularity* on *Firm performance*, accounting for approximately 80% of the effect ($0.548/\ 0.689 = 79.536\%$ of the effect is due to *Servitization depth*). These results challenge Hypothesis 3a, which proposed a greater association between *Firm performance* and *Product Modularity* rather than an extensive level of *Servitization Depth*. For Intermediate services, the direct effect of *Product modularity* on *Firm performance* significantly outweighs the impact of *Servitization depth*, indicating that *Product modularity* bears the brunt of the influence ($Total\ effect = 0.812 - 0.034 = 0.778$). This finding rejects Hypothesis 3b, which anticipated significant contributions from both *Product modularity* and increased *Servitization depth*, with an increasing mediating role for the latter. For Advanced service, the indirect influence of *Servitization depth* exceeds the direct effect of *Product modularity* on *Firm performance*, constituting roughly 60% of the total effect ($Total\ effect = 0.246 + 0.364 = 0.610$), $0.364/\ 0.610 = 59.672\%$ of the effect is due to *Servitization depth*). This finding partially supports Hypothesis 3c, affirming an amplified mediating role of *Servitization depth* between *Product modularity* and *Firm performance* for Advanced services.

These findings demonstrate that when manufacturers offer Base and Advanced services, *Servitization depth* plays a significant mediating role in the relationship between *Product Modularity* and *Firm performance*. Conversely, in the context of Intermediate service offerings, *Servitization depth*'s role diminishes, with *Product modularity* largely accounting for the *Firm performance* impact. The entire set of hypotheses is summarized in Table 2.

Table 2. Mediation and moderation analysis and bootstrap results for indirect effect (N=204)

Variables	**Beta**	**se**	**t**	**p**
Hypothesis 1: *Product modularity* → *Firm performance*	0.361	0.056	2.281	<0.001
Hypothesis 2: *Product modularity* → *Servitization depth* → *Firm performance*	**Bootstrap result for indirect effect**			
	I. Effect 0.345	Se 0.023	LL 95% CI > 0.013	UL 95% CI < 0.684
Hypotheses 3a, 3b, and 3c: *Service types moderation effect*	Base Total=0.689 Direct=0.141 Indirect=0.548		Intermediate Total=0.778 Direct=0.812 Indirect=-0.034	Advanced Total=0.610 Direct=0.246 Indirect=0.364

Finally, Figure 2 depicts the direct and indirect influences of *Product modularity* on *Firm performance*, mediated by *Servitization depth*, varying according to the *Service types*.

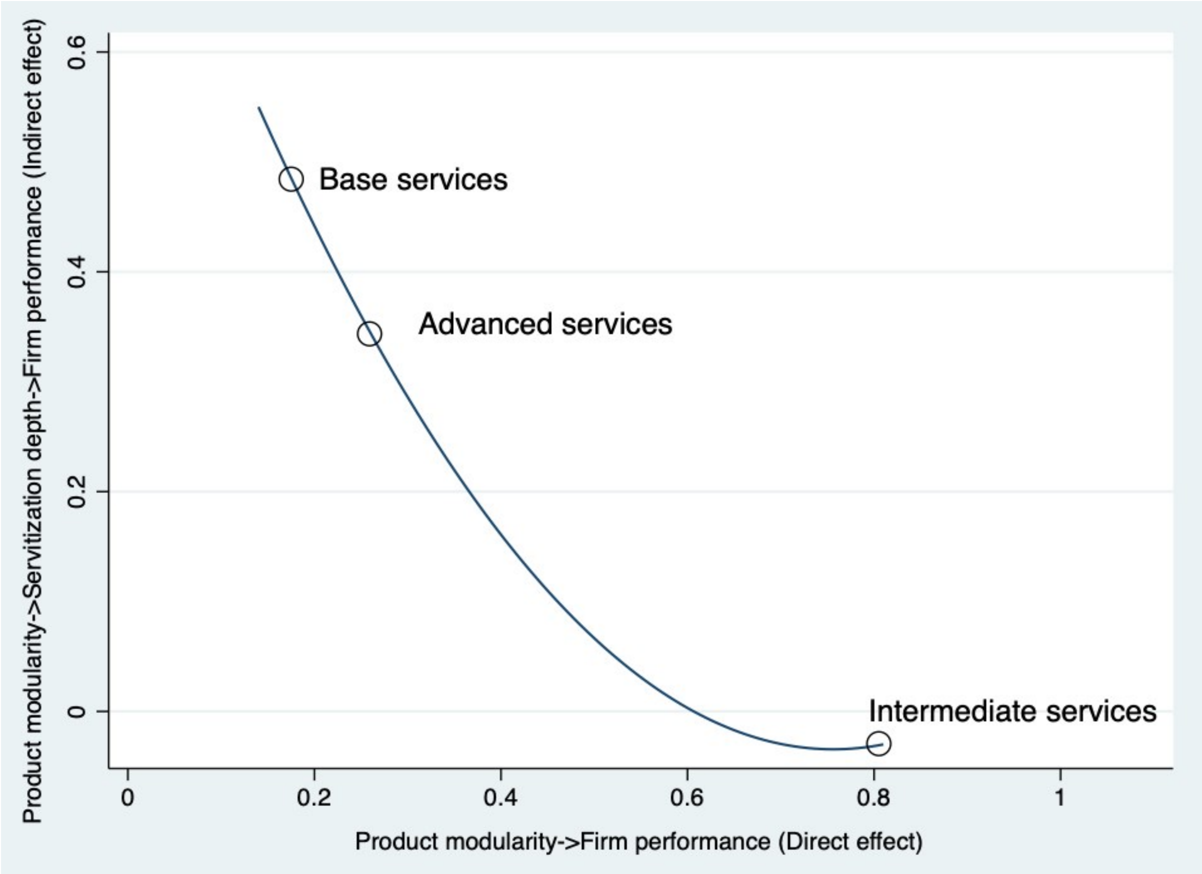

Figure 2. Direct and indirect effects of product modularity on firm performance, stratified by service types

5. Discussion and conclusion

The study investigates the interplay between product modularity, servitization depth, service types, and firm performance. As one of the few quantitative studies exploring product modularity in the context of servitization, this research seeks to answer the question of the extent to which firm performance is influenced by product modularity and servitization depth, and how does its role vary across the service types. The study contributes to the servitization literature by consolidating previous qualitative findings and providing new insights.

5.1. Theoretical contribution

The study proposes three core theoretical contributions to the servitization literature (Khanra et al. 2021). First, it further illustrates the association between product modularity and servitization literature (Salonen, Rajala, and Virtanen 2018; Rajala et al. 2019; Johnson et al. 2021; Hsuan, Jovanovic, and Clemente 2021). Earlier research, largely qualitative, implied that product modularity augments the success of servitized firms through enabling efficient design, flexible customization, and diminished differentiation costs (Rajala et al. 2019). However, the transformation of service orientation, delivery systems, and resource base that servitization demands (denoted as servitization depth) simultaneously play a crucial role in successful servitization (Ayala, Gerstlberger, and Frank 2019; Sousa and da Silveira 2017). This research probes quantitatively the interplay between product modularity and servitization depth and delivers fresh insights into how they collectively impact firm performance (Wang, Lai, and Shou 2018). Therefore, the study propels the theoretical advancement of the existing literature by adopting a quantitative approach to examine the antecedents of firm performance in servitization literature (Kastalli and Looy 2013; Li et al. 2023; Wang, Lai, and Shou 2018). The results underscore that both product modularity and servitization depth are instrumental for firm performance. Crucially, it demonstrates that the influence of product modularity on firm performance is amplified when firms concurrently enhance their servitization depth across the three dimensions of servitization depth as defined and adapted in this study (Ayala, Gerstlberger, and Frank 2019).

Secondly, this research provides an in-depth analysis of the interplay between servitization depth, product modularity, and the service types offered by manufacturing firms. While literature explored the impact of business model openness (Visnjic, Neely, and Jovanovic 2018), industry conditions (Visnjic, Ringov, and Arts 2019), and product complexity (Raddats et al. 2016) on the choice of service types, this study indicates that base and advanced services significantly rely on servitization depth, whereas intermediate services are more influenced by product modularity. While this result, albeit partially supporting our hypotheses, confirms that the relationship between product modularity and servitization depth as contingent upon the service types provided. This result is also counterintuitive. The success of base services would be expected to be more reliant on product modularity than servitization depth (Sousa and Silveira 2017). Yet, an additional interpretation of our findings concerning the reliance of base services on servitization depth rather than product modularity is that base services, to be effective, often require extensive servitization depth in form of external partners that cover vast geographical areas and collaborate in service delivery, ensure proximity to customers, and high-quality base services (Hullova, Laczko, and Frishammar 2019; Parida and Jovanovic 2022). This also signifies that manufacturers should prioritize developing servitization depth initially, specifically front-end service capabilities (Jovanovic et al. 2019; Valtakoski and Witell 2018), as they serve as a foundation for more complex services (e.g., advanced services) and align directly with the provision of base services (Sousa and Silveira 2017). Similarly, our results indicating a strong dependency of intermediate services on product modularity, instead of servitization depth, reinforce the argument that digitalization favors standardized modular products that underpin various intermediate services (e.g., remote monitoring services) (Grubic 2018; Grubic and Jennions 2018; Frank et al. 2019). Additionally, the reduced dependency on servitization depth could be due to the inherently scalable nature of intermediate services (Grubic 2018; Linde, Frishammar, and Parida 2021). Finally, the case of advanced services is event more nuanced. These services, which include aspects like support agreements or outcome-based contracting (Visnjic et al. 2017), require a balance between product modularity and servitization depth. Therefore, as manufacturers move along the product-service continuum from base to advanced services, the reliance shifts from primarily servitization depth for base services, to product modularity for intermediate services, and eventually to a balanced yet greater dependence on servitization depth for advanced services. This path is frequently termed as "transitioning into an industrializer", a strategy commonly adopted to alleviate the substantial expenses related to the provision of advanced services (Kowalkowski et al. 2015).

Finally, while our prediction concerning service types was not fully corroborated, the insights gained from our findings may afford firms valuable information to strategically select the service types that optimizes firm performance during servitization transition (Kowalkowski et al. 2015). In particular, this study augments the growing literature on various paths and configurations in servitization transition (Visnjic, Neely, and Jovanovic 2018; Kowalkowski et al. 2015; Gaiardelli, Martinez, and Cavalieri 2015; Lütjen, Tietze, and Schultz 2017; Peillon, Pellegrin, and Burlat 2015) by considering product architectural choices (Zhou et al. 2020) and servitization depth as manufacturers configure their service portfolios (Eggert et al. 2011; Rabetino, Kohtamäki, and Gebauer 2017). Therefore, the study represents a valuable contribution to the strategic positioning within the servitization literature (Rabetino, Kohtamäki, and Gebauer 2017).

5.1. Managerial implications

The findings of this research carry strategic implications for manufacturing firms with modular products. It is essential to recognize that product modularity in isolation does not guarantee success in servitization. Our study reveals that base, intermediate, and advanced services derive varying benefits from product modularity in relation to and with servitization depth. This requires a strategic approach by managers when making service business development and investment decisions, customizing strategies to suit the unique requirements of their respective service types. For instance, if a firm provides advanced services necessitating a high degree of customization and personalization, or base services that rely on a substantial number of partners, a greater investment in servitization depth might be warranted. This could involve fostering a robust service-oriented culture, creating a rich service resource base, and building advanced delivery systems. Conversely, if a firm offers intermediate services, extensive investment in servitization depth may not be as critical. The emphasis could instead be on designing more modular products that could easily be digitally enabled and can leverage information communication technologies (ICT) in scaling intermediate services rapidly and efficiently. Therefore, by comprehending the benefits and trade-offs associated with different service types and the role of servitization depth, managers can make informed decisions, setting their firms on a servitization trajectory.

5.2 Limitations and future research directions

Like all research, this study has its limitations, which present opportunities for further scholarly exploration. Primarily, the sample was limited to manufacturing firms within the UK and Germany, which could affect the generalizability of our findings. For broader applicability, future research should encompass a wider geographical scope. This study additionally focused on the degree of product modularity within manufacturing firms, specifically considering aspects of functionality and variability. An interesting avenue for future research could be exploring the drivers behind a firm's decision to modularize products. Factors such as customization, interoperability, recombination, disassembly, or repair, but also service-related drivers such as service architecture and modularity (Brax et al. 2017; Voss and Hsuan 2009), could all play a role and warrant investigation. A more nuanced understanding of these motivations could offer insights into why base services are less reliant on product modularity compared to intermediate services. Therefore, in subsequent studies, a more comprehensive evaluation of product architectures in servitization is warranted (Jovanovic, Engwall, and Jerbrant 2016; Raddats et al. 2016). Additionally, research designs and methodologies could consider both modular and integral product architectures, recognizing that firms may employ either or a mix of both (Hsuan, Jovanovic, and Clemente 2021). This aspect is significant as it could influence servitization trajectories, service types, and overall firm performance.

Finally, while indicators of firm performance of this study were in line with other studies (Wang, Lai, and Shou 2018), our outcome variables may have not captured the entire picture. Future research could expand the range of outcome variables to include aspects such as customer satisfaction, supplier profit performance, service-specific profit division, and resource productivity. This expanded perspective could lead to a more comprehensive understanding of servitization success and its driving factors.

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Appendix 1: Questionnaire

Descriptives

Please answer the following descriptive questions in relation to your company.

What is the name of your company?

Annual sales revenue

- Less than £50 million
- £50 < …. < £100 million
- £100 < … < £250 million
- £250 < … < £1,000 million
- £1,000 < … < £5,000 million
- Over £5,000 million

Number of employees

- 100 < …. < 499
- 500 < …. < 999
- 1,000 < …. < 4,999
- 5,000 < …. < 9,999
- Over 10,000

Please describe your main business focus (e.g., B2B, B2C, other)

Please describe how your company's portfolio is composed (in percentage): (products/services e.g., 60% product, 40% services)

Industry sector (SIC CODES)

- Metal mining
- Coal mining
- Oil and gas extraction
- Mining and quarrying of non-metallic minerals, except fuels
- Building construction-general contractors and operative builders
- Heavy construction other than build construction contractors
- Construction-special trade contractors
- Food and kindred products
- Tabaco products manufacturing
- Textile mill products manufacturing
- Apparel and other finished products made from fabrics and similar materials manufacturing
- Lumber and wood products, except furniture manufacturing
- Furniture and fixtures manufacturing
- Petroleum refining and related industries
- Rubber and miscellaneous plastics products manufacturing
- Primary metal industries manufacturing
- Fabricated metal products, except machinery, and transportation equipment
- Industrial and commercial machinery and computer equipment
- Electronic and other electrical equipment and components, except computer equipment
- Transportation equipment manufacturing
- Measuring, analysing, and controlling instruments; photographic, medical and optical goods; watches and clocks manufacturing
- Miscellaneous manufacturing industries
- Photographic equipment and supplies
- Other (please type your industry)

Respondent position
Senior leadership/executive
Senior manager
Manager
Individual contributor
Respondent location
Germany
UK
Other

SERVITIZATION DEPTH
(adapted from Ayala et al. 2019).

Dimension: Service Orientation

SO1. The service offering in my company is considered a strategical aspect for our competitiveness.

SO2. We compete primarily in services differentiation.

SO3. Our services are offered spontaneously when a customer need is identified.

SO4. We understand well how our customer perceives the value of our services.

SO5. We are more customer-oriented than our competitors.

Dimension: Resource Base

RB1. To develop our services, we frequently develop new competences inside our company.

RB2. The human capital (individual expertise) of my company is a source of competitive advantage.

RB3. The internal knowledge owned by my company is considered a source of competitive advantage.

RB4. Our company is very flexible to market changes, being able to adapt quickly.

Dimension: Delivery system

AS1. Our services and products are developed together and simultaneously.

AS2. The service area has an active role in taking strategic decisions about new products and markets.

AS3. Our different functional areas often work together in the development of new products and solutions.

AS4. Our customers/partners have active participation in the development of our new products and services.

AS5. Other business units of our company are very active in new product and service development.

FIRM PERFORMANCE (Adapted from Sila, 2007; Wang, Lai, and Shou 2018; Zhou, Yan, Zhao, and Guo, 2020).
We use a five-point Likert scale (1- strongly disagree to 5- strongly agree) to measure the extent to which a respondent agreed that each performance dimension grew faster than competitors' performance dimensions in the three years after the manufacturer adopted a digital servitization strategy.

FP1. Our market share grew faster than our competitors in the three years after we adopted a digital servitization strategy.

FP2. Our profit grew faster than our competitors in the three years after we adopted a digital servitization strategy.

FP3. Our return on total assets grew faster than our competitors in the three years after we adopted a digital servitization strategy.

FP4. Our overall competitive position grew faster than our competitors in the three years after we adopted a digital servitization strategy.
FP5. Our number of successful new product/service introductions grew faster than our competitors in the three years after we adopted a digital servitization strategy.

SERVICE TYPES
(adapted from Baines and Lightfoot 2013)

What basic product support services are offered? (answers Y/N)
BAS1. Product/Equipment Provision
BAS2. Spare Parts
BAS3. Warranty
What intermediate services are offered?
INT1. Scheduled Maintenance
INT2. Helpdesk
INT3. Training
INT4. Field Service
INT5. Condition Monitoring
What advanced services are offered?
ADV1. Support Agreements
ADV2. Revenue through Use Contract
ADV3 Outsourcing/Rental
ADV4. Risk and Reward Sharing Contract
PRODUCT MODULARITY
(adapted from Vickery et al. 2016)

Please indicate to what degree you agree with the following statements on a scale of 1 (strongly disagree) to 5 (strongly agree)

Dropped For our products, we can make changes in components without changing other components

FUN1 For our products, functions can be directly added or deleted by adding or removing components

FUN2 Our product components have standardized interfaces
FUN3 Our products can be decomposed into separate modules

FUN4 Our products are designed to be easily reconfigured

VAR1 Our products have interchangeable features and options

VAR2 Our products are designed to enable the swapping of components

VAR3 The interfaces of our product components are designed to accept a variety of other components

VAR4 Our product components are able to accept a wide range of complements (such as modules or peripherals)