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Uncovering Productivity Gains of Digital and Green Servitization: Implications from the Automotive Industry

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Abstract: The growing industrial concern about sustainability challenges has driven vehicle and auto parts manufacturers to adopt service capabilities as a way to maintain competitiveness in compliance with environmental regulations. As a result, automakers have progressively integrated digital and green service initiatives to support operations and address environmental issues effectively. The present study examined the effect of digital and green servitization on the firm's productivity. To test their effect quantitatively, this study used the ORBIS database to construct a multi-country sample containing 228 companies in the automotive industry. Our findings indicate that implementation of digital and green servitization is positively associated with higher productivity outcomes once the two forms of servitization coexist and operate jointly. Moreover, the results of the study underscore the importance of establishing a successional pathway of implementation priorities. Our evidence suggests that firms willing to offer green services should consider offering digital services first, as this is the only way to obtain productivity gains from green servitization.

Keywords: sustainability; digital servitization; green servitization; performance benefits

1. Introduction

Sustainability has gained considerable attention from organizations attempting to interweave environmental, social and economic performance in their business strategy [1,2]. Its implementation has induced companies to be more involved in complex global social-ecological challenges, such as climate change, biodiversity loss or natural resources depletion [3]. In effect, sustainability adoption has become a strategic imperative and a fundamental market requirement capable of influencing long-term organizational and economic viability and success [4]. Hence, over the years, companies have gradually been transitioning towards responsible environmental behavior and sustainable management of their operations [5], conceiving sustainability as an opportunity for compliance with stakeholders and government legislation, building difficult-to-replicate core competences, and optimizing firm operations and performance [6].

One of the industries that has felt the incremental shift towards sustainability is the automotive industry, characterized by its significant and permanent effect on the environment [7]. Throughout the last century, this industry moved from a *Fordist* production system—in which the key elements of firm performance were principally economies of scale, efficiency and promotion—to a smart system of production, in which the entire supply chain, from design to customer loyalty programs, is connected and monitored through digital technologies. Such evolving environments have forced automobile manufacturers to reinvent themselves in terms of strategic aims, product design and marketing strategies [8]. New entrant Tesla Motors exemplifies this new conceptualization of the business model. Other industry leaders, such as Toyota, Volvo, Nissan and BMW, are just some of the firms committed to adopting new technologies to develop more environmentally friendly processes, communication channels and products (e.g., electric and hybrid vehicles).

The automotive industry (for purposes of our study) constitutes a product system that relates both directly and indirectly to economic wealth creation. Because this industry has a profound impact on the natural and human environment [9], it plays a significant role in social and environmental development in a sustainability context. Vehicle and auto parts manufacturers have been under scrutiny by regulatory agencies to ensure that they satisfy environmental standards and reduce the impact of both their products and their manufacturing processes [10]. This pressure has led them to adopt innovative business strategies and leading-edge information and communication technologies (ICTs) to achieve environmental and economic performance targets [11].

The search for new ways to combine sustainable development with competitiveness has induced automotive companies to adopt service capabilities [12], leading them increasingly to embrace servitization. Technically, servitization refers to the process through which manufacturing companies complement their traditional (product-based) offerings by integrating services into their business operations [13]. In the automotive industry, servitization has served as the guiding strategy to sustain and benefit from the incorporation of services, both in product development and throughout product life cycle [12].

Servitization has enabled automakers to support operations through the inclusion of *digital services* [14]. These services represent a non-material solution to support data-intensive production processes, while providing companies with advanced business intelligence and analytic tools crucial to information availability and better-informed decision making in manufacturing [15,16]. Companies' progressive implementation shapes a new organizational scenario, in which labor-intensive and time-consuming procedures are dynamized by intangible software solutions. These new opportunities increase competitiveness in industrial production [17], positioning *digital servitization* as an innovative and dependable strategy capable of optimizing operations and improving firm performance [14,18].

Additionally, for sustainability purposes, ICTs have promoted the implementation of *green services* [19]. Green services provide automakers with the necessary means to monitor and control sustainable initiatives (e.g., restoration and site remediation, waste and emissions reduction, raw material recycling, maintenance and repair management, and water and energy conservation) aimed at achieving cleaner production methods [20,21]. Their implementation in manufacturing firms entails the effective entwining of digital capabilities and environmentally-focused initiatives in convergence with the firm's sustainability and performance objectives. Green service adoption provides the groundwork for *green servitization* of business as a broader strategic approach addressing interests or utilities beyond the conventional boundaries of the firm, including environmental issues [22].

A growing body of quantitative research assesses the relationship between servitization and productivity. Recent articles show that firms implementing servitization practices significantly increase operating margins [23–25], sales growth [26,27], employment [14] and key performance indicators [17]. They also seem to reduce environmental impacts [28–30]. However, servitization also has underlying commercial and operational risks that raise the probability of default [31]. Interestingly, the servitization literature lacks research that focuses on productivity as a measure of economic performance, even though productivity has long been considered a standard measure of economic performance for traditional manufacturers [32].

The literature has discussed the potential of servitization for sustainability extensively [33–35]. Several studies indicate the relevance of servitization to enhancing sustainability in the automotive industry [36–39]. Although these studies contribute great insights, most papers focus on individual and direct effects of servitization within the firm, omitting broader (e.g., environmental or social) effects and thus painting only a partial picture of servitization's influence. Further, although existing research has analyzed different levels and types of servitization (e.g., [27]), to the best of our knowledge, no research so far has attempted to analyze the dichotomization of digital and green servitization in manufacturing companies and the effect of this dichotomous productivity.

To address this gap, our paper aims to assess empirically the effect of digital and green servitization on the firm's productivity through a study sample of 228 firms in 21 countries in the automotive industry. The information was gathered from the ORBIS database for the period 2015–2016. Our original research design follows recent trends in servitization research [40], exploiting the information provided by ORBIS on secondary industries to determine which manufacturing firms (first industry) also offer services (second industry). This approach enables us to construct binary measures for digital and green services implementation.

Further, this study seeks to reveal the importance of establishing an optimal implementation order of servitization strategies to achieve sustainability and economic performance. To that end, we draw on a recent paper by Agrawal and Bellos [22] that reports a positive relationship between servitization, sustainability and productivity.

Our results indicate that exploitation of digital and green servitization strategies is positively associated with higher productivity outcomes once the two strategies coexist and operate simultaneously. The main empirical contribution of this paper is its empirical insights into the effect of a dual-servitization strategy (digital and green, separately and jointly) on the firm's performance. The paper also attempts to identify a feasible pathway for implementation of these strategies, one in which digital servitization can be considered as a primary requisite for achieving productivity gains from green servitization.

The paper is organized as follows. Section 2 presents a theoretical review of sustainability and digital servitization and formulates the hypotheses. In Section 3, we describe the methodology and data used to assess the economic performance of digital and green servitization. Section 4 provides the results of the research based on analysis of secondary data gathered from the ORBIS database. Subsequently, Section 5 presents discussion and implications. Finally, Section 6 provides conclusions and a prospectus for future research.

2. Literature Review and Hypothesis Development

2.1. Sustainability in the Automotive Industry

Increased awareness of sustainability matters is having an enormous impact on the automotive industry [41]. Over the years, this industry has experienced stringent environmental pressures in the form of governmental regulations to reduce emissions and waste throughout vehicle production [21]. In so doing, automakers must cope with two main challenges—complying with environmental standards and ensuring the firm's successful long-term performance [42].

To overcome regulatory pressures, maintain sustainable operations and achieve a better image, automotive companies have increasingly adopted sustainable initiatives throughout all phases of a product's life cycle, from extraction of raw materials including design, production and distribution to use of the product by consumers and disposal at the end of the product's life cycle [43]. These initiatives provide automakers with a framework for pursuing organizational competitiveness through sustainable operations, targeting CO_2 emissions reduction, reuse, remanufacture/repair and recycling of materials or products, green design, green marketing, sustainable transportation and product end-of-life practices [21]. Recent studies indicate that sustainable initiatives have become the norm by which automakers now operate, satisfy regulations and improve competitive position [44,45].

Renault motors, for example, has focused its operations on increasing the "reuse rate" for products and raw materials in current processes and on developing new processes, especially for recycling materials in end-of-life vehicles [46]. At Ford, component recycling has been facilitated by input substitutes, such as bio-based composite materials [47]. Similarly, BMW recently launched the i3, a carbon-fiber-bodied car that is 95% recyclable [48]. Such sustainable initiatives are expected to provide automakers with a set of benefits, such as: (1) enhanced resource optimization (materials savings) resulting from continued substitution, reuse and recycling of production inputs; (2) better utilization of by-products in new product development; and (3) lower product cost (e.g., due to material substitution and conversion of waste into valuable forms) [49]. Further, Toyota, which plans to have a combustion-engine-free supply chain by 2050 [50], has implemented "Sustainable plants" committed to reducing CO_2 emissions by replacing fossil fuels with photovoltaic power generation systems [51]. Volvo has introduced "Silane-based technology" to recycle water in water-consuming production processes [46], improving (4) energy and water optimization during production process. As to (5) energy optimization during product use, Michelin has launched energy-saving tires, and Audi Motors has created energy-efficient LED lighting [49].

Sustainable initiatives have also become an effective catalyst to satisfy the increasing environmental commitment of stakeholders [52], improve corporate image and increase customer satisfaction [53]. Over the past few years, a new type of automobile consumer has appeared, one who demands more sustainable operations and is willing to criticize and condemn unsustainable manufacturing practices [54]. The Volkswagen scandal, in which the company used "defeat devices" to cheat emissions tests, severely threatened the company's image and undermined public trust in the brand [55], with significant financial consequences; an overall sales drop of 7.9% in 2015 [56]. Further, sustainable demands are producing high demand for cars that are safer for our environment [57]. When Nissan Motors launched its Leaf model, the first 100% electric car, customer response was overwhelming, with sales of over 110,000 units globally [58]. A few weeks after Tesla Motors announced launch of the company's first mass-market vehicle in 2016, over 400,000 customers worldwide pre-ordered the new Model 3, for which first deliveries were expected at the end of 2017 [59]. Sustainability has become much more than an environmental approach to meeting governmental regulations, pursuing competitiveness and satisfying the growing demand for green products (hybrid and electric vehicles) in the automotive industry [53]. It has become a philosophy that supports corporate objectives (e.g., enhances company image) and determines long-term success [37,41].

Rather than trying to capture the entire realm of sustainability (social, environmental and economic [1]), we limit investigation here to the latter two elements, following the eco-efficiency approach [60]. This approach focuses on improving sustainability by addressing environmental and economic performance simultaneously within organizations, specifically, by examining the environmental and productivity gains of green and digital servitization strategies in automobile manufacturers. This approach is in no way intended to deny or disparage the existence of possible social improvements, due mainly to the "social utility" behind environmental protection and the tight interrelation between the sustainability elements [61].

2.2. Digital and Green Servitization

2.2.1. Digital Servitization (Productivity-Oriented Services)

Recent advances in ICTs and the emergence of digitalization and smart products [62] have introduced new pathways through which services can be provided, giving rise to a wide range of new application spheres [14]. Within this context, organizations have begun to introduce digital technologies to bridge products and services and to expand the scope of their offerings [63]. This new paradigm, in which product and service propositions can be offered and delivered completely through digital channels, is publicized as digital servitization [14,18].

Digital servitization may be described as the sub-branch of servitization that implies the dematerialization of physical goods by electronic means for the purpose of bolstering firms´ performance and competitiveness through the support of ICT capabilities [64,65].

For automobile manufacturers, this strategy creates opportunities to extend their business model through digital interactions with stakeholders, dynamizing co-creation and value creation processes in supply chain [66]. It also enables firms to reach out to customers digitally and thus rapidly to sense and respond to changing customer needs [67]. Volvo, for example, has focused its customer strategy on digital platforms to develop a more direct relationship to end-customers and to deliver what the company calls *a premium customer experience* [68]. Digital servitization provides companies with unprecedented possibilities for creation of competitive advantages in the digital economy, advantages derived from enhanced capacity to transform information as a source of value creation [69]. Automobile manufacturers can transform the information about mobility behavior or vehicle usage into inputs for optimizing production processes and products, and improving the efficacy of marketing strategies [70].

Digital servitization can also raise productivity in vehicle manufacturing (product development) through the use of advanced technological tools such as business analytics and virtual modeling to optimize decision making [16,65,71], reduce development costs and speed up time to market [14]. To cite one instance, Ford Motors implemented digital prototyping into its operations, reducing costs and time of developing components. For a single engine manifold, developing and creating a prototype using tool-based manufacturing costs approximately $500,000 and takes four months. Through digital prototyping, Ford developed multiple iterations of prototypes of this component in just four days at a cost of only $3000 [72]. Hence, digital servitization opens new channels for better-coordinated operations [14], enabling improved resource allocation and visibility of assets (through virtualization) to decrease planning time, facilitate better-coordinated inventory pooling and optimize deliveries [73]. All of the above-mentioned features make it possible to reduce supply chain uncertainty and demand distortion, enabling companies to operate more efficiently.

2.2.2. Green Servitization (Environmentally-Oriented Services)

Widespread adoption of digital communications in operations, as well as the need to satisfy environmental regulations, has promoted convergence of a service concept specifically designed to enhance digitally sustainable initiatives in both product development and product life cycle. These services are called green services [19].

In manufacturing settings, green services represent a digital proposition to support operations in compliance with environmental regulations. They thus facilitate alignment of a company's operations with environmental constraints to ensure sustainability of operations. At European level, the European Union (EU) has introduced the end-of-life (ELV) directive to enhance environmental sustainability from vehicle manufacturing by promoting initiatives such as collection, reuse and recycling of components through the entire process [74]. To this end, green services provide support for assessing and controlling proper execution of initiatives established by regulatory frameworks through monitoring, measuring and analyzing information to control sustainability performance on a timely basis [72,75].

At the product level, green services may offer multiple opportunities to enhance sustainability throughout the product's life cycle, providing sustainable functioning patterns to diminish the environmental impacts associated with product utility. As automobiles become more digitally-enabled, they are expected to be increasingly equipped with green services that improve vehicles' sustainable utility. Toyota, for instance, has implemented an eco-driving service that supports the driver in optimizing route choice and driving behavior to reduce vehicle emissions, generating significant benefits in fuel saving and improved air quality [76]. Green services may also serve as a mechanism through which to achieve sustainability recognition, provide a differentiated (sustainability-oriented) corporate image [53] and satisfy increased customer awareness of environmental issues [57]. Such services may enable companies to gain competitive advantages derived from sustainable management [77].

Progressive adoption of green services can thus steer companies towards green servitization of business, in which the decision to include a service component in the company's operational and business activities stems from the need to decrease environmental impacts both in product development and throughout product life-cycle. Within this context, green servitization can be regarded as a business strategy that seeks to achieve corporate goals for sustainability through provision of green services. It is thus reasonable to posit that the implementation of green servitization provides a way to move away from unsustainable patterns of production and product performance, launching companies towards a sustainability continuum.

2.3. Developing Testable Hypotheses

The adoption of digital servitization in product-based firms has been closely related to efficient, reliable, cost-efficient operations [14,16]. Such benefits are directly associated with the technological attributes of digitalization [15,18,65,69,71], which enable companies to identify and virtualize assets, facilitating allocation of resources [73], reducing development costs [72], decreasing planning times [13,65] and shortening time to market [14]. All of the above result in higher operating margins [23–25], while implementation of digital servitization gives companies sophisticated mechanisms to exploit value from data [62,63,69,71], facilitating and streamlining decision-making processes to respond to internal and external contingencies in a timely and effective manner [15,17]. Thus, digital servitization enables faster response to customer demands [14,18,65,67] and improves the quality of service provision [16,69], increasing the firm's performance and competitiveness [26,27]. As a result of these considerations, we propose the following hypothesis:

Hypothesis 1 (H1): *Manufacturing firms implementing digital servitization (productivity-oriented services) have higher productivity gains than manufacturing firms not implementing digital servitization.*

Literature suggests that the implementation of services alters the logic of industrial production, improving operations and producing positive environmental effects [12,22,37]. Previous studies also indicate that the use of digital technologies facilitates proper execution of sustainable initiatives in manufacturing [67,75]. Such initiatives are primarily oriented to enhancing operations performance through optimization of resources (via repair, reuse and recycling) [21,46–48]. Based on this research, we argue that green servitization functions to coordinate and align (digitally) both sustainable and operational goals [49,72]. In doing so, companies can monitor and ensure proper functioning of their sustainable initiatives and obtain a set of operational benefits such as reduced consumption of new resources/inputs by recycling and transforming waste into secondary raw materials (by-products) [21,47,49], and utilizing recycled components as an input in current and new product development [37,47]. Such activities may help companies to reduce production costs, achieving economies of scale, lowering energy consumption and enhancing organizational competitiveness [21,45,54]. Based on this argument, we propose the following hypothesis:

Hypothesis 2 (H2): *Manufacturing firms implementing green servitization (environmentally-oriented services) have higher productivity gains than manufacturing firms not implementing green servitization.*

We argue that implementation of a dual servitization strategy (digital and green servitization) provides organizations with the necessary technological toolkit to enhance both manufacturing and environmental performance [45,67,76]. Our theoretical assertion is based on two mutually reinforcing arguments. Firstly, through the use of digital channels, digital servitization fosters and facilitates communication flow in operations [66], enabling cost-efficient allocation and distribution of resources [73]. Secondly, green servitization uses the digital infrastructure to monitor correct functioning of sustainable initiatives that focus on effective management of resources, promoting repair, reuse and recycling of waste [21,46]. Through such complementarity, both service concepts aim to optimize (efficiently and sustainably) the total pool of resources through the support of ICT capabilities. Such synergies not only enable multiple operational benefits (described above) [14,16,17,64,65] but also provide the necessary means to meet environmental regulatory requirements [42,74]. Arguing a positive mutually reinforcing effect between digital and green servitization in operations performance, we therefore hypothesize the following:

Hypothesis 3 (H3): *Manufacturing firms implementing a dual-servitization strategy of digital and green servitization (productivity- and environmentally-oriented services) have higher productivity gains than manufacturing firms implementing green or digital servitization in isolation.*

3. Method

The automotive industry can be defined as a high-precision, technology-intensive, integrated industry [67] characterized by severe competition at all levels of its value chain, high R&D expenditures and long development times [8]. As one of the most important sectors for a country's production, economy and trade, this industry generates over $2.5 trillion in revenue per year globally, corresponding to roughly 10% of the Gross Domestic Product in developed countries [10]. In Europe, the automotive industry employs over 5.7% of the total EU workforce, more than 12 million people. With more than €50 billion invested annually in R&D, the industry is deemed a key driver of knowledge and innovation development [78]. Toyota's eco-division, for example, spends an average of nearly $1 million an hour on R&D of cars and technologies of the future [8].

On a global scale, Greater China remains at the forefront of automotive producers with a market share of 30% of global production (5.6 million vehicles), followed by North America and Europe with 23% (4.3 million vehicles) and 19% (3.5 million vehicles) of market share, respectively. In a distant fourth and fifth place are South Asia with 13% (2.3 million vehicles) and Japan/Korea with 4.9% (1.6 million vehicles), respectively [78,79].

The significant impact of the automotive industry on the environment has attracted increased research in the last decade [8–10,20,37,41,45,47,51,55,61,70,74,76]. This impact encompasses the effect on the environment of energy, material and water consumption, producing pollution and requiring waste disposal [20,21,49]. The automotive industry is thus facing many demands related to reduction of CO_2 emissions and end-of-life automobile management [21,43,74]. These demands involve both burdens and opportunities for developing new business models. To reveal the role of new services based on sustainable and digital solutions, we developed a sample of commercial and passenger automotive vehicle manufacturers operating in different countries. To construct the sample, we resorted to the ORBIS database on the years 2015 and 2016. In addition to accounting and financial information, ORBIS offers information of primary and secondary sectors of activity. This permits identifying product firms that also participate in service sectors [40]. We enriched the analysis by providing additional information about countries´ environmental conditions in which selected firms operate. In doing so, we merged ORBIS firm-level data with the country-level Centre (JRC)/PBL Netherlands Environmental Assessment Agency data.

ORBIS reports information on over 200 million private firms worldwide (for more information, visit https://www.bvdinfo.com). We restricted firm size to companies with over 50 employees to exclude small firms from the sample, a common approach to avoid productivity outliers [80]. Economic activity was determined using the North American Industry Classification System (NAICS) codes. ORBIS enables selection of primary plus additional secondary activities. In the first stage, primary codes related to the automotive categories were chosen: NAICS codes 3361 "Motor vehicle manufacturing", 3362 "Motor Vehicle Body and Trailer Manufacturing" and 3363 "Motor Vehicle Parts Manufacturing". Through this procedure, we obtained 2762 firms. In the second stage, servitized manufacturing firms were selected through the secondary codes proposed by Wong and He [81] for determining servitization and digital services' activities: codes 518 "Data Processing, Hosting, and Related Services"; 519 "Other Information Services"; and 54 "Professional, Scientific, and Technical Services". The codes proposed by Gomes et al. [40] were used to identify manufacturers' sustainable activities: 56 "Administrative and Support and Waste Management and Remediation Services" and 811 "Repair and Maintenance". This stage produced a sample of 228 servitized companies operating in 21 different countries. At this stage it is worth emphasizing that we have made the voluntary decision of not including non-servitized car manufacturers in the sample. The inclusion of secondary sectors in the annual accountancy reports is not compulsory in most countries. This means that firms without a secondary sector might be eventually operating in other economic sectors and therefore they could potentially be incorrectly classified as non-servitized firms. For this reason, in this research, we did not incorporate a randomized control group of non-servitized car manufacturers.

We must also control for market specificities. Countries with higher levels of emissions may provide incentives for firms to reduce emissions by implementing more advanced wage management approaches or different types of technologies (e.g., renewable energies, electric or hybrid engines). The added value of green services could therefore depend on market characteristics. To analyze CO_2 emissions by country, we gathered data from the EDGAR (Emission Database for Global Atmospheric Research) and the European Commission's Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. Our analysis is based on the "Global per capita CO_2 emissions from fossil fuel use and cement production 1970–2015" dataset, from which we obtained the unit *Ton (Mg) CO_2 per capita and per year* used in our analysis. For more information, visit the Emission Database for Global Atmospheric Research (EDGAR), release version 4.3.2. http://edgar.jrc.ec.europe.eu.

Variables

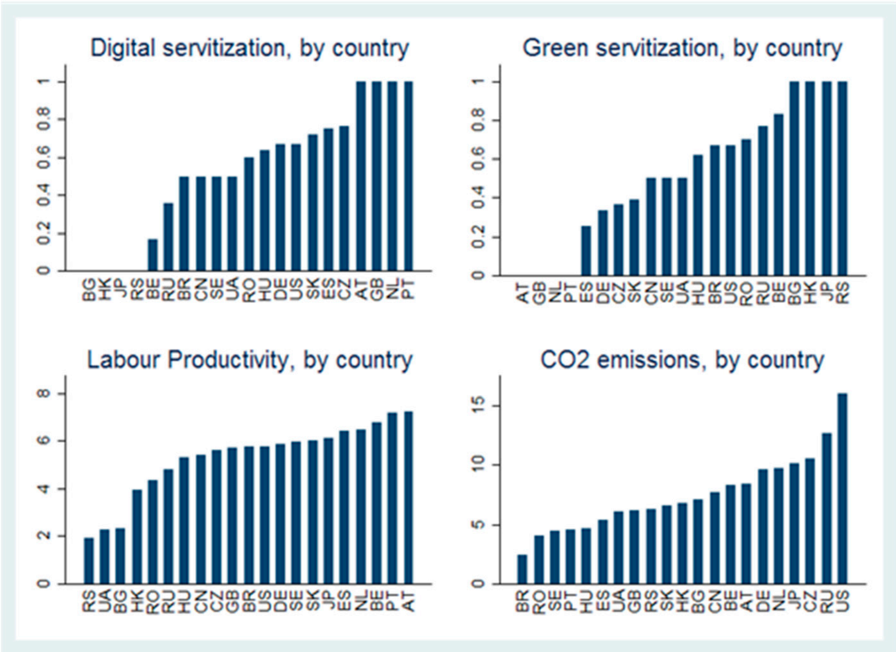
To test the empirical hypotheses developed in the theoretical section we created several variables to measure central constructs. The details on how productivity, servitization strategies, CO_2 emissions and control variables were computed, as well as the basic descriptive statistics, are provided in the following paragraphs.

Productivity: Productivity is an economic measure of firm competitiveness that explains whether firms make efficient use of their inputs to generate outputs. This measure is normally used to analyze outcomes in SMEs [82]. In our analysis, this measure is the dependent variable. Following Luo and Bu [83] and Pessoa and Van Reenen [84], it was calculated as the ratio of total sales over employees. In tables and figures, this variable is log transformed to decrease its skewness so that it better fits a normal distribution.

Dual-Servitization Strategy: Dual-servitization strategy is composed of two variables. *Digital Servitization* is a dummy variable that takes a value of 1 if the firm offers digital services in addition to products and 0 otherwise. This means that the primary economic sector of the firm is the automotive industry and the secondary sector is digital services (see description of the database for more detail). In our sample, 137 firms provided digital services (60%). Similarly, *Green Servitization* is a dummy variable that takes a value of 1 if the firm offers green services in addition to products and 0 otherwise. This means that the primary economic sector of the firm is the automotive industry and the secondary sector is green services. In our sample, 126 firms provided green services (55.3%). As ORBIS provides all secondary sectors, it is possible to identify the firms that offer both digital and green services. In our sample, 35 firms provided both digital and green services (15.3%). The total sample therefore contains 102 firms offering only digital services, 91 firms offering only green services and 35 firms offering both, or engaging in what this study describes as a dual-servitization strategy.

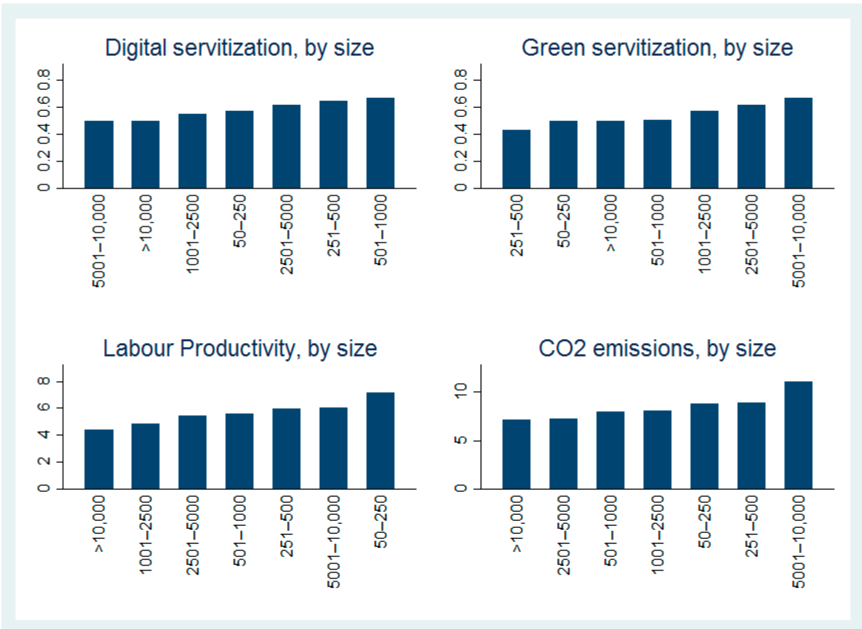
CO_2 emissions: Because the adoption of sustainable services and their relation to productivity could be influenced by the level of emissions at country level, studies control for CO_2 emissions per capita measured in tons (Mg). This variable is lagged one year to allow time for changes in firm behavior and productivity due to environmental issues. The data were obtained from the European Commission.

Our study included subsidiaries located in 21 countries (Austria (AT), Belgium (BE), Bulgaria (BG), Brazil (BR), China (CN), Czech Republic (CZ), Germany (DE), Spain (ES), United Kingdom (GB), Hong Kong (HK), Hungary (HU), Japan (JP), Netherlands (NL), Portugal (PT), Romania (RO), Serbia (RS), Russian Federation (RU), Sweden (SE), Slovakia (SK), Ukraine (UA), and United States of America (US)), which can be divided into seven different size categories based on level of employment (50–250, 251–500, 501–1000, 1001–2500, 2501–5000, 5001–10,000, and >10,000). Figures 1 and 2 summarize the variables of interest mentioned above by country and size. The study also provides firms' information for two different time periods (2015 and 2016), based on data availability. The results shown in tables control for fixed effects of specific country, size and year.



(**a**) (**b**)

Figure 1. Variables of interest, by country: (**a**) digital servitization and labor productivity, by country; and (**b**) green servitization and CO_2 emissions, by country. The horizontal axis refers to the ISO two-digit country code and the vertical axis to the mean of the variable of interest.



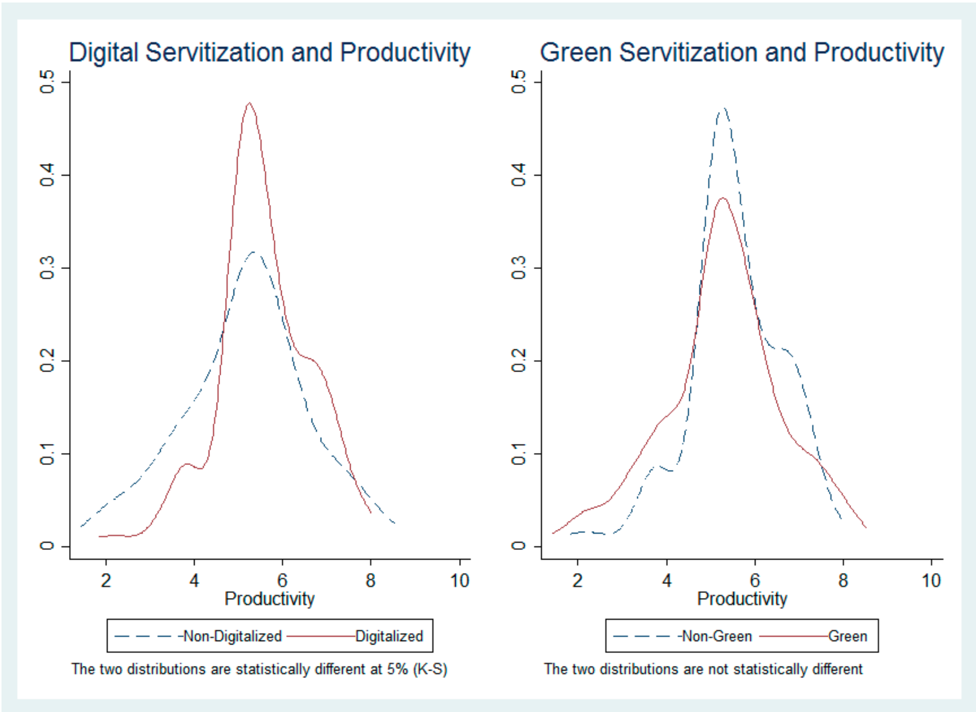
(**a**) (**b**)

Figure 2. Variables of interest by size: (**a**) digital servitization and labor productivity, by size; and (**b**) green servitization and CO_2 emissions, by size. The horizontal axis represents classification of companies based on number of employees and the vertical axis the mean of the variable for interest.

4. Results

As a warm-up exercise, we computed labor productivity distributions for firms undertaking digital (or green) servitization and compared them to the productivity distribution of their counterparts, i.e., non-digitalized (or non-green) firms. This enables us to test graphically whether the most productive firms are servitized. The Kolmogorov–Smirnov test [85] provides statistical validity for the comparison of distributions. This test can thus establish a graphical bivariate correlation between the variables of interest.

As shown in Figure 3, firms undertaking digital servitization are more productive than non-digitalized firms to a statistically significant degree (at 5%). No relevant productivity differences exist between firms undertaking green servitization and firms not implementing services with a sustainable component. A visual interpretation of the figure thus supports partial validity of Hypothesis 1, which states that undertaking digital servitization increases firm productivity. Our evidence does not, however, support the conclusion that green servitization enhances productivity.



(**a**) (**b**)

Figure 3. Labor productivity distributions: (**a**) digital servitization and labor productivity; and (**b**) green servitization and labor productivity.

Although the comparison of productivity distributions is instructive, the hypotheses must be tested through multivariate analysis, as other factors may explain differences in productivity. We thus divide our research strategy into two stages. The first aims at testing the direct and independent effects of digital and green servitization on productivity. It does so by comparing productivity levels for green and digital servitization in two separate OLS regression models that include a variety of control variables, such as the (lagged) emissions of CO_2 on the former, and the fixed effects of country, size and year. The results of this stage are presented in Columns 1 and 2 of Table 1. Since the dependent variable is in logarithmic form, the parameters shown in the table must be transformed by calculating the true effect, which equals exp(β)-1.

Column 1 shows that firms undertaking digital servitization show a positive and significant direct effect on labor productivity. According to our estimates, firms gain 19.01% in productivity after including digital services in their offer. This result is significant at 5%, confirming Hypothesis 1. Regarding Column 2, our results reject Hypothesis 2, as green services in isolation do not seem to have a direct effect on labor productivity.

Table 1. OLS analysis.

	(1) Full Sample	(2) Full Sample	(3) Full Sample	(4) Digital Sample	(5) Green Sample
Digital	0.174 **				0.314 ***
	(0.0626)				(0.0852)
Green		−0.00226		0.171	
		(0.102)		(0.134)	
Digital * Green			0.288 **		
			(0.112)		
CO_2 (t − 1)	−2.607	−2.571	−2.583	−4.704 ***	0.0635
	(1.935)	(2.014)	(2.003)	(1.109)	(2.258)
Constant	29.53	29.35	29.45	48.54 ***	3.999
	(16.19)	(16.89)	(16.79)	(9.253)	(10.01)
Country FE	YES	YES	YES	YES	YES
Size FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES
N	228	228	228	137	126
R2	0.523	0.519	0.526	0.526	0.593

Dependent variable: Ln Labor productivity. Clustered by size (standard errors in parentheses). ** $p < 0.05$, *** $p < 0.01$.

The second stage of our analysis is to analyze the combined effect of green and digital servitization on labor productivity. Column 3 reports the results of the interaction effect of digital and green servitization. This approach estimates the productivity gains obtained by implementing a dual-servitization strategy. According to our estimates, firms deploying both types of servitization are 33.4% more productive than firms only implementing one servitization strategy in isolation. As the result is statistically significant at 5%, this synergetic effect empirically supports Hypothesis 3.

The results so far provide no indication (either for or against) of an optimal pathway for introducing these services in the firm's portfolio. To resolve this issue, we perform a multivariate analysis for the subsamples of firms (Columns 4 and 5) that have implemented digital (Column 4) and green (Column 5) servitization. We first analyze the coefficients in Column 5. According to our estimates, in the sub-sample of firms implementing green servitization, firms that have both digital and green servitization are 36.9% more productive than firms that implement green servitization only. This result is statistically significant at 1%, and we interpret it to mean that obtaining productivity gains from green services requires firms to implement digital services first. The same logic does not apply to the sub-sample of firms implementing digital services, in which the coefficient for green servitization is not statistically significant. These results confirm Hypothesis 3, while demonstrating that digital servitization is a primary requisite for green servitization implementation.

5. Discussion and Implications

This paper has analyzed the effect of digital and green servitization on firms' productivity. We selected this approach because most previous servitization literature has analyzed the impact on other outcome variables, including profit margin and growth but omitting productivity. To the best of our knowledge, only Lodefalk [32] used this important indicator of economic performance. More specifically, our analysis followed the eco-efficiency approach, considering the effect of servitization (digital and green) on environmental and economic performance improvements [60]. Overall, our findings for the automotive industry reflect a positive association of the effect of a dual-servitization (digital and green) strategy with improvements in firm's economic and environmental competitiveness. This result reinforces with previous studies [12,22] that demonstrate the positive environmental and economic effects of services in manufacturing settings.

The economic implications of digital and green services are first analyzed individually. An important finding of this study is the relevance of digital servitization for firm productivity, confirming Hypothesis 1. This result can be ascribed mainly to the technological attributes of digital services, which enable better coordination of operations [14,16,17], driving firm performance and competitiveness [23–27]; and to the nature of the automotive industry, which is characterized by high investment in R&D and high technological sophistication [8,67,78].

The results also suggest that green servitization in isolation does not have a direct effect on firm performance, leading us to reject Hypothesis 2. This result may be attributed to the fact that environmental initiatives do not impact performance when implemented in isolation, without considering economic benefits. This result agrees with those of Zhu and Sarkis [44] and Luthra et al. [45], who argued that obtaining sustainability outcomes requires aligning sustainability goals with firm strategy.

The main contribution of this paper is its demonstration of the positive effect of a dual-servitization strategy (digital and green, in which these two types of servitization coexist and perform jointly) on productivity gains, supporting Hypothesis 3. Companies' deployment of both types of servitization may be more productive (33.4%) because digital services have the capability to enhance resource management (allocation, distribution, availability) in operations [13,14,65,73]. Further, the positive effect of green services in upgrading resource utilization through sustainable initiatives (repair, reuse, recycling) [21,46–48] can promote circularity of resources (closing material loops) [37]. When complementarity is achieved, both service strategies contribute to superior optimization of the pool of resources, enhancing the firm's performance and competitiveness [21,45,54]. Finally, the results obtained reveal a feasible implementation pathway that could lead companies to enhanced productivity gains. The results presented in this article thus provide empirical evidence that digital servitization is a primary requisite for achieving higher productivity performance. This result is consistent with previous empirical studies [44], which report that productivity performance should be a top priority for manufacturers.

On the empirical side, additional research is thus valuable to test whether digital and green services can impact other performance variables. We performed additional analysis, changing the outcome variable (the dependent variable) to a standard measure of financial returns—earnings before interests and taxes (EBIT). The parameters were qualitatively the same but became statistically nonsignificant, contradicting prior literature that analyses the relationship between servitization and financial performance [23,24]. One plausible explanation for this unexpected result is that, as in Visjnic, Kastalli and Van Looy [25], our results come from subsidiaries. It is common practice for multinationals in the automotive industry to transfer profits to the subsidiaries located in countries with lower tax rates. Financial profits in our sample thus do not reflect the real economic outcome obtained by subsidiaries, which is better reflected in our measure of labor productivity. Nevertheless, more research is needed to clarify the relationship of digital and green services to various outcome variables and whether these services should be developed in-house, outsourced or in partnership with external service providers [86,87].

This study has managerial and policy implications. Manufacturing firms attempting to climb the environmentally-friendly-production ladder through servitization must have prior experience with digitalization. Otherwise, their environmental benefits will not translate into productivity gains. Additionally, one role of government is to enhance private investment in activities that produce fewer negative externalities for society, for example, activities that lower levels of waste and emissions. Policy makers must ensure that the digital infrastructure and digital skills available in the economy meet high standards to enable manufacturing firms to implement green services successfully. This policy recommendation is especially important in developing economies, where manufacturing firms may have limited access to digital technologies, such as low broadband speed and labor skills.

The study has three limitations that open avenues for future empirical research. First, our analysis is cross-sectional and therefore does not capture the dynamic nature of the factors that determine the implementation of servitization strategies and how this dynamism translates into productivity gains for firms. Introducing more periods in the analysis would enable us to control for reverse causality and other problems of endogeneity common in cross-section settings. Second, our method of identifying servitization in manufacturing uses secondary sectors. The main limitation of this research design is that disclosure of secondary sectors is not compulsory in most countries, preventing construction of a sample of non-servitized firms. In the future, with more government regulation, we expect that it will be possible to conduct similar analyses including a control sample of non-servitized firms. Relatedly, the secondary sectors identified are generic to increase the sample size. Going forward, when more product firms declare their activities in other economic sectors it might be possible to utilize more specific sectors, 4–5-digit industry codes. Third, the study cannot identify the firm-level emissions of either the target firm (producer) or the firm using green services (client). These data are important to assessing the broader benefits of green servitization. Future research should thus include firm-level measures of the negative externalities underlying production of goods, including CO_2 emissions.

6. Conclusions and a Prospectus for Future Research

From a theoretical standpoint, this paper divides servitization of manufacturing into two differentiated types of service: green and digital. The strategy of offering both types of services is described as a dual-servitization strategy. Dichotomizing servitization is an important contribution to the growing servitization community. The empirical aspect of the study provides evidence from the automotive industry, which reflects the dual servitization approach in the shift from *Fordist* production to a *Teslaist* mindset that includes synergetic digital and green services to enhance product offerings. Our empirical results support this view. Firms implementing a dual servitization strategy are more productive than firms implementing one service strategy in isolation. We also find that green services in isolation do not generate productivity gains. These results are important for the sustainability community, as they suggest that digital technologies can enhance the economic value of environmentally-friendly approaches to production. As the results are far from being generalizable to all manufacturing settings, we acknowledge that further research is needed to test our hypotheses in other industrial contexts.

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