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DOI:
10.1108/JMTM-12-2020-0498

This is the author's copy of a Manuscript published by **Emerald** in *Journal of Manufacturing Technology Management*, accepted 17th August 2021.

Global Value Chain breadth and firm productivity: The enhancing effect of Industry 4.0

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Abstract
Purpose – Global value chains (GVC) incorporate internationally fragmented sources of knowledge so as to increase global competitiveness and performance. This paper sheds light on the role of Industry 4.0 technological capabilities in facilitating knowledge access from international linkages and improving firm productivity.
Design/methodology/approach – Drawing on organizational learning research, the present study argues that the relationship between GVC breadth, analyzed in respect to the geographical fragmentation of production facilities, and productivity follows an inverted U-shaped pattern that can be explained by the interplay between external knowledge access and the coordination costs associated with GVC breadth. We test our predictions using a purpose-built survey that was carried out among a sample of 426 Spanish manufacturing firms.
Findings – Our results indicate that organizations adhering to a traditional manufacturing system are able to benefit from fewer transnational relationships (concretely 11 foreign facilities) in the search for productivity improvements. This can be largely attributed to the marginal value of the knowledge accessed and the costs of coordinating international counterparts´ production and knowledge transfer. However, our study reveals that the adoption of Industry 4.0 technologies have the potential to broaden optimal GVC breadth, in terms of the number of linkages to interrelate with (concretely 131 foreign facilities) so as to obtain productivity gains whilst mitigating the complexities associated with coordination.
Originality – The study unveils that Industry 4.0 technologies enable management of broader GVC breadth, facilitating knowledge access and counteracting coordination costs from international counterparts.
Keywords – Global manufacturing networks, Industry 4.0, Organizational learning, Creativity
Paper type - Research paper.

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1. Introduction

Production is often fragmented into a wider set of processes and tasks which, in many cases, take place across a number of different countries simultaneously (Saliola and Zanfei, 2009; Pietrobelli and Rabellotti, 2011). Accordingly, companies increasingly engage in very broad and complex global value chains (GVCs), which, in the extreme, build a global factory with a high level of commercial integration in all intermediate processes (Narula, 2018; Buckley *et al*., 2020). As such, companies that hold production-centred operations can establish production facilities in a large number of countries through joint ventures or setting up subsidiaries (De Marchi *et al*., 2018). An example of this is the company Irizar, a bus production company founded in the north of Spain in 1964 that expanded its production to China, India, Morocco, Brazil, and Mexico with the entry of the 21st century (Simón-Elorz *et al*., 2005). Bearing in mind this global productive setting, the underlying question of this work is where the optimal point is (in terms of international linkages) in the international manufacturing expansion.

Previous studies have shown that participating in a GVC provides a gateway to international markets and renders an increase in business specialization (Gereffi, 2019). Thus, in the present work we consider GVC participation as an opportunity to acquire new knowledge and promote creativity (Harvey and Novicevic, 2002). In particular, by drawing on organizational learning theories (Woodman *et al*., 1993), we argue that knowledge acquisition arising from broader global value chains has a positive effect on the productivity of companies (Criscuolo and Timmis, 2017). However, as in any learning curve, these positive effects suffer from diminishing marginal returns (Asimakopoulos *et al*., 2020). On the other hand, we also argue that a broader GVC breadth can increase coordination costs, making decreasing returns a possibility. Altogether, the combination of both arguments indicates the existence of an optimal GVC breadth, which in empirical terms is reflected in an inverted U-shaped relationship (García-García *et al*. 2017; Chen *et al*. 2018) between GVC breadth and firm productivity, and in practical terms is reflected in an optimal number of countries in which firms should operate their production facilities.

Additionally, there is growing interest in how the adoption of Industry 4.0 technologies can improve knowledge acquisition and coordination management in global value chains

(Strange and Zucchella, 2017; Szalavetz, 2019). It is therefore of practical and academic relevance to explore the potential impact of Industry 4.0 technologies in designing and managing global value creation networks (Wang and Hsu, 2021) allowing to optimize individual buyer–supplier communication and coordination as well as entire value chains (Veile *et al*., 2020).

We argue that digital technologies under the umbrella of Industry 4.0 (e.g. the internet of things (IoT), big data and analytics, robotic systems, etc.) have the potential to influence both GVC configuration and geographical dispersion (Chen, 2019). In particular, we propose and empirically validate that the use of Industry 4.0 technologies enhances the benefits of knowledge acquisition and attenuates coordination costs, enabling a rightward shift in the optimal level of GVC breadth.

We test the hypotheses on a purpose-built survey carried out among a sample of medium- and large-sized (MLEs) Spanish manufacturing firms. MLEs firms are of two-fold importance when analyzing GVC and Industry 4.0: firstly, MLEs play an important role in most of the global manufacturing industries to expand prime manufacturers’ production capacities; and secondly, Industry 4.0 specifically opens new business opportunities for MLEs to access global markets (Chen, 2020). Data obtained from administering the survey to 426 firms were fused with accounting and financial data from the Bureau Van Dijk (BvD) to make the study more robust in relation to monetary values (e.g. firm revenues).

The contributions of the study are threefold. First, we find that external sources of knowledge add value, but in contrast to other international business (IB) practices in which learning curves apply (i.e. diminishing marginal returns in exporting); we are the first to find that in the context of GVCs, coordination costs play an important role and may reverse the positive effects of external knowledge access leading to decreasing returns, i.e. reaching a point in which more external knowledge may deteriorate. Second, the study demonstrates that in complex environments, Industry 4.0 enhances knowledge acquisition and creativity in a form that boosts firm’s capacity to operate in complex production networks. This responds to recent calls for more research on the benefits of Industry 4.0 within technology management (Ortt *et al*., 2020), industrial marketing (Vendrell-Herrero *et al.*, 2021a) and IB (Alcácer *et al*., 2016). Third, this study contributes to the globalization vs. de-globalization debate (Martin, 2018; James, 2018), by providing strong evidence that through technological advancements it is practically impossible to put barriers on globalization.

The paper is organized as follows: the Introduction, Section two, which presents background literature and sets out empirical hypotheses; Section three, which describes the data, variables and empirical design; Section four, which shows the results; and Section five, which discusses the conclusions and their implications and limitations.

2. Theoretical background and hypotheses

IB studies have long been focused on exploring the link between internationalization and organizational learning mechanisms, under the notion that both location and learning sourcing are symbiotic components for business opportunities as well as industrial upgrading on a global scale (Chiva *et al*., 2014; Cano-Kollmann *et al*., 2016). From this perspective, companies benefit from knowledge residing outside the firm boundaries (i.e. external sources of knowledge) through different channels/inputs (e.g. peers, customers, suppliers and competitors), gaining access to different types of knowledge along the value chain, and thereby extending firms' opportunities to learn (Love *et al*., 2014; Van Beers and Zand, 2014).

Additionally, in the context of international diversification [i.e. the extent to which a firm engages in operations in several foreign countries with diverse market environments (Strange and Humphrey, 2019)] the exposure to external/foreign counterparts provides access to new and diverse knowledge from a variety of market and cultural perspectives e.g. rules, regulations, norms, and values (Ghauri and Park, 2012). Within this domain, the global fragmentation of production activities, referred to as global value chain (GVC) production (Pietrobelli and Rabellotti, 2011) ascribes to the notion that the more foreign partners the company interacts with, the more information they bring into the focal relationship (Saliola and Zanfei, 2009). The GVC approach is hence deemed to extend the likelihood to explore novel knowledge combinations, promote knowledge diffusion, learn from best practices, and consequently enhance productivity and performance (Mudambi *et al*., 2017; Asimakopoulos *et al*., 2020).

While this approach encompasses accessing new knowledge as a crucial factor for successful transnational inter-firm linkages, it also calls for effective knowledge access coordination mechanisms within the GVC context (Meyer *et al*., 2011; De Marchi *et al*., 2018). On this basis, the learning process expands because firms operate in highly diversified environments with access to novel information, and wherein such information diversity inspires individuals to create new ideas (Leoni, 2019; Korzynski *et al*., 2019). Hence, in due course, creativity spreads by nurturing ideas, creative skills and expertise in organizational processes, asserting itself as a crucial resource for firms performing globally (Harvey and Novicevic, 2002; de Vasconcellos *et al*., 2019; Cristofaro *et al*., 2021).

At this juncture, and aiming to strengthen the efficiency of disaggregated knowledge sources, firms increasingly rely on new digital technologies and drive towards the Industry 4.0 paradigm to increase connectivity, interaction, and coordination of knowledge flows between systems, people, and machines (Ghobakhloo, 2018; Vendrell-Herrero *et al*., 2018; Chen, 2019; Szalavetz, 2019). Hence, as GVC becomes ever more interconnected and digitalized, traditional relations between GVC links move toward a network of upstream and downstream connections that enhance knowledge flows and learning possibilities (Soontornthum *et al*., 2020). Industry 4.0 therefore stimulates the integration of creative ideas into the development of products, processes and services (Vendrell-Herrero and Wilson, 2017); configuring an interconnected industrial value-creation process that breaks down international borders (Müller *et al*., 2018). For the purpose of this study, GVC is analyzed in respect to the geographical dispersion/fragmentation of production facilities (Strange and Humphrey, 2019). Particularly, we conceptualize this attribute in terms of *breadth* in line with the work by Love *et al*. (2014) on innovation linkages. In this manner, we define breadth as the number of countries comprised in a GVC relationship. We do so because we catalogue each country as an external source of knowledge participating in a GVC framework. Likewise, we rely on the organizational learning theory (Woodman *et al*., 1993) to provide theoretical linkages between knowledge transfer and creativity. For this purpose, we build on the organizational creativity literature perspective on external knowledge access and learning as a means for motivating creativity in international operations (Song *et al*., 2019).

Altogether, we claim that the internationally fragmented sources of knowledge incentivizing learning and creativity may be affected through coordination costs from interdependent relationships in a GVC—with performance implications. Specifically, we argue that the relationship between GVC breadth and productivity follows a non-monotonic, inverted U-shaped pattern that can be explained by the interplay between external knowledge access stimulating learning and creativity and the increasing coordination costs of GVC breadth.

2.1 Global value chain breadth, organizational learning, creativity, and productivity

As previously noted, we expect the relationship between GVC´s breadth and productivity to follow an inverted U-shaped pattern. We therefore argue that as GVC breadth expands—to more countries—they can benefit from more external knowledge sourcing. External knowledge acquisition and utilization are considered to be decisive factors in determining performance and maintaining competitive advantage in IB (Cano-Kollmann *et al*., 2016; De Marchi *et al*., 2018). Since external knowledge sources provide access to valuable industry and location-specific information (Mudambi *et al*., 2017; Narula, 2018), we suggest that external GVC linkages augment the uniqueness of firms' existing knowledge bases and capabilities (Mukherjee *et al*., 2019). Accordingly, they are better able to obtain larger productivity gains from building unique knowledge-based assets such as human capital, research and development (R&D), technology, and creative outputs, which define the value and competitiveness of final goods and/or services (Criscuolo and Timmis, 2017).

Apart from providing a solid and permanent basis for competitiveness, external knowledge sources promote information exchange and organizational learning (Korzynski *et al*., 2019; Soontornthum *et al*., 2020). Organizational learning encapsulates the process from external knowledge acquisition to knowledge internalization and application (Yu *et al*., 2013). Likewise, external knowledge sources, along with the ability to internalize and apply learning, reduce organizational inertia and strengthen firm's creativity (de Vasconcellos *et al*., 2019). By these means, creativity emerges, spurred by the exposure to different sources of knowledge and socialization (as a learning mechanism), establishing new connections or re-connecting with counterparts/peers (Giustiniano *et al*., 2016).

However, drawing on concepts from organizational learning theory (Woodman *et al*., 1993), we propose that there is a threshold to GVC´s breadth to reap the benefits of external knowledge sources. This threshold will be largely determined by the emergence of two obstacles to GVC breadth: diminishing marginal value of knowledge acquisition (Li and

Hsieh, 2009) and coordination costs (Meyer *et al*., 2011), two issues that often intertwine in GVC relationships and external knowledge sourcing (Asimakopoulos *et al*., 2020).

GVCs are considered to be platforms for knowledge flow and inter-firm collaboration and, thereby important sources to transfer and access foreign knowledge (see, for instance, De Marchi *et al*., 2018; Gereffi, 2019; Soontornthum *et al*., 2020). Members of a GVC often have diverse functional backgrounds and belong to different business units, characteristics that serve as a useful way to access diverse sources of knowledge (Buckley *et al*., 2020). Accordingly, within this framework, purposive inflows and outflows of knowledge between inter-organizational linkages promote learning, innovation, and better creative outcomes from social interactions (Giustiniano *et al*., 2016; Korzynski *et al*., 2019). However, as GVC breadth widens, the probability of diminishing returns of external knowledge access grows. This might be attributed to the fact that the learning curve of external knowledge reaches a point where the value of the external knowledge transferred at inter-firm level becomes negligible, which in turn decreases the probability of an effective learning process after reaching a maximum point (Li and Hsieh, 2009). Thus, the wider the GVC breadth, the lower the likelihood of GVC partners accessing new and valuable knowledge shared from their international counterparts.

Knowledge transfer in GVCs is not static, but rather a dynamic process where the nature of the knowledge accessed serves as the base for building new knowledge or reconfiguring existing knowledge (Chiva *et al*., 2014). Within this framework, different sources of external knowledge from geographically distant production activities intertwine, thus the effective coordination of activities among the geographically dispersed units becomes critical for GVC performance (Mukherjee *et al*., 2019; Munjal *et al*., 2021). However, the coordination of knowledge sourcing is not free of complexity, and lack or failure in the use of effective mechanisms can be detrimental to knowledge integration among GVC inter-firm linkages (Wang *et al*., 2019). To cope with this challenge, literature stresses the role played by communication mechanisms, such as face-to-face meetings, e-mails, telephone calls, videoconferences, and other means often adopted to coordinate knowledge transfer in GVCs (Adenfelt, 2010). Accordingly, as GVC breadth widens, it demands more effective coordination mechanisms to adequately manage geographical, cultural, and institutional barriers in order to harvest the benefits of the knowledge accessed from GVC linkages.

However, the escalating complexity and coordination costs when dealing with a wider GVC breadth can increase to a point that might lead to decreasing returns, where the value of the knowledge accessed is likely to be outweighed by the emergence of coordination diseconomies (Meyer *et al*., 2011).

Taking into account these arguments, we propose that GVC breadth will have a positive impact on firms' productivity because it enables them to access external knowledge sources that enrich existing knowledge and promote learning and creativity (Criscuolo and Timmis, 2017; Korzynski *et al*., 2019). Nonetheless, it must be noted that beyond a certain threshold, the benefits that firms achieve by accessing external knowledge can rapidly be offset by the existence of coordination diseconomies (Meyer *et al*., 2011). As such, we predict that the relationship between GVC breadth and firm productivity follows an inverted U-shaped pattern. Accordingly, we formulate the following hypothesis.

H1. The relationship between global value chain (GVC) breadth and firm productivity displays an inverted U-shaped pattern.

2.2 The impact of Industry 4.0 on managing Global Value Chains

Industry 4.0 represents a new industrial paradigm of manufacturing systems, which integrates a set of emerging and converging digital technologies such as the Internet of Things (IoT), Sensors, Automation, Radio-Frequency Identification (RFID), Big data analytics, Augmented reality, and Cloud computing among others, to provide end-to-end support to the entire value chain (Strange and Zucchella, 2017; Ghadge *et al*., 2020; Wang and Hsu, 2021). At a more detailed level, Industry 4.0 encompasses automated systems that enable customization, agility and speed in manufacturing and service operations by providing data from various devices, sensors and tools oriented towards industrial value-creation (Müller *et al*., 2018; Dos Santos *et al*., 2020). Within this paradigm, value chain is integrated into a manufacturing ecosystem where data, information, and knowledge are at the core to coordinate value chain activities and tasks, monitor production performance, and support decision-making—without time-space constraints (Alcácer *et al*., 2016; Veile *et al*., 2020).

Prior studies argue that Industry 4.0 technologies have the potential to redesign the entire value chain network from upstream to downstream—improving operational processes, reducing costs and risks—by increased cooperation, automation and data sharing between partners (Haddud *et al*., 2017; Ghobakhloo, 2018). In the same vein, the emerging literature on "Supply Chain 4.0" sustains that Industry 4.0 technologies have remarkable implications for GVC design, reconfiguration, operations as well as performance (Frederico *et al*., 2019)[1]. Therefore, Industry 4.0 technologies not only enable organizations to significantly improve their operational efficiency through effective management of production processes, but also contribute to the competitive edge in globally-spread value chains (Chen, 2020). By and large, literature posits that Industry 4.0 technologies can yield a range of opportunities in value chains, such as enhanced product customization, real-time data analytics, increased visibility (virtualization), autonomous monitoring and control, dynamic product design and development and enhanced productivity. (Müller *et al*., 2018; Vendrell-Herrero *et al.*, 2021a). This evolving manufacturing environment, however, poses new requirements for manufacturing companies, including the integration of an advanced technological infrastructure (objects, networks, data services, etc.) in the value chain (Ghadge *et al*., 2020), the assurance of privacy and security in data transaction, i.e. cybersecurity (Klingenberg *et al*., 2019), internal and external technological integration and interoperability of systems (Ghobakhloo, 2018), and accessing human talent with the required knowledge and skills (Flores *et al*., 2020).

Within the Industry 4.0 framework, people, machines, and resources are transparently intercommunicated by computing systems, enabling value chain members to systematically access, store and process large amounts of multi-source heterogeneous data (Tao *et al*., 2018; Veile *et al*., 2020). By means of automatized and intelligent data processing capabilities, data inputs are translated into interpretable insights (e.g. via interactive data visualization) and actionable recommendations (e.g. via historical data analysis) about manufacturing execution (Klingenberg *et al*., 2019; Ortt *et al*., 2020). Hence, through analytics and machine-learning algorithms, voluminous data captured from value chain production systems are transformed in information and, in time, into a retrievable pool of knowledge (e.g. manufacturing and

[1] Though this study focuses on value chain coordination, we adopt recent trends in supply chain management that are complementary to our argument. Thus, we acknowledge that although supply chain and value chain have important differences, ultimately they both focus on the management of input flows in production systems. The supply chain focuses on access to raw materials and purchase of generic components, whereas the value chain focuses on the manufacture of specific components/parts of the final product.

product knowledge) for manufacturers to make informed and rational operational decisions (Bustinza *et al.*, 2019; Vendrell-Herrero *et al*., 2021b). Accordingly, the structured collection and analysis of large data sets facilitate more knowledgeable decisions concerning whether, when, and how to adjust manufacturing processes (Szalavetz, 2019).

From an Industry 4.0 perspective, the interconnection between systems, assets, and machines configure smart grids all along the value chain so as to control and coordinate production processes seamlessly (Dos Santos *et al*., 2020). To do so, traditional industrial machinery (e.g. manufacturing equipment) and products are endowed with sensors, RFID, and actuators to gather and transfer information (Porter and Heppelmann, 2015). This allows monitoring all the different steps of the manufacturing process in real time and, through data analytics and virtualization technologies, tracing possible factors affecting manufacturing resources/processes (Haddud *et al*., 2017). Hence, organizations are able to detect possible malfunctions (e.g. product quality defects or equipment faults), and make timely adjustments so as to ensure greater uniformity in manufacturing operations (Tao *et al*., 2018). Additionally, within Industry 4.0 settings, augmented-reality-based systems enable manufacturing processes (e.g. warehouse operations) to be performed remotely and in real time, facilitating thereby the normal execution of production processes, without time or geographical location constraints (Chen, 2020).

Based on the above arguments, we posit that firms' adoption of Industry 4.0 technologies broadens the inverted U-shaped relationship between GVC breadth and firm productivity. In particular, we suggest that the absorptive capacity embedded in Industry 4.0 technological advances upgrade GVC capabilities to access timely and refined information/knowledge from external sources as well as increased coordination mechanisms for geographically disperse GVC linkages. In light of this, Industry 4.0 adoption has the potential to reduce the negative effect of diminishing marginal returns of knowledge acquisition (Li and Hsieh, 2009) and coordination diseconomies (Meyer *et al*., 2011). Accordingly, we formulate the following hypothesis:

H2. Industry 4.0 will broaden the inverted U-shaped relationship between global value chain (GVC) and firm productivity.

Figure 1 exhibits the proposed framework in order to better visualize the predicted interrelationships captured in the study's hypotheses. On the whole, both hypotheses suggest an inverted U-shaped relationship between GVC breadth and productivity, which underpins the existence of an optimum number of countries that should be involved in the GVC (μ). However, Hypothesis 2 implies that in relation to traditional manufacturing firms, those manufacturers that adopt Industry 4.0 will be able to reach out to more foreign countries before experiencing decreasing returns ($\mu_{traditional} < \mu_{Industry4.0}$).

--- Insert Figure 1 about here ---

3. Method

3.1. Database

This study seeks to uncover contemporary implementation of Industry 4.0 technologies among medium-and large-sized (MLEs) Spanish manufacturing firms[2]. Spain is considered to be a relevant context as it has been experiencing a progressive industrial transformation (and upgrading), from labour intensive production to knowledge intensive manufacturing under the concept of Industry 4.0 (Braña, 2019; Ortin-Angel and Vendrell-Herrero, 2014). To identify the population of firms we utilize the SABI database, a service of Bureau Van Dijk (BvD) (http://sabi.bvdep.com), which provides a good representation of all strata of the Spanish manufacturing population.

The population of firms varies in size from 50 to more than 1,000 employees that work in industries with manufacturing NAICS codes 31 to 33. These codes include industries such as food, beverage, and textile processing (NAICS 31); non-mineral manufacturing together with wood, petroleum, plastics and chemical processes, and the pharmaceutical industry (NAICS 32); and mineral manufacturing, as well as the construction of hardware, vehicles, machines, turbines, and engines (NAICS 33). We identified a population of 7,552 firms.

Firms were contacted via Computer-Aided Telephone Interviewing using procedures supported by the literature. This method is cost-effective and can measure behavior of interest

[2] We adopt the OECD's business size classification. This indicator is measured as the number of people employed by an enterprise. Concretely, we build our analysis upon medium-sized enterprises (50 to 249 employees) and large enterprises (250 or more employees). More information is available at the following link: https://data.oecd.org/entrepreneur/enterprises-by-business-size.htm

(Couper, 2000). During November and December 2018, companies were contacted by phone until we obtained 438 responses, being 426 of them fully complete answers. Respondent firms were found to be representative since the sectoral and size composition were close to that of the total population. Once the survey was completed, it was merged with the SABI database to ensure that the monetary values of interest including revenues and profits for the current (2018) and subsequent (2019) periods were fully objective.

3.2. Variables

The conceptual model developed for this study is based on three key constructs, namely Total factor productivity (TFP), Global value chain (GVC) breadth, and Industry 4.0 technologies. We therefore provide a detailed description on how these constructs have been operationalized below. Further technical information is displayed in Table 1.

--- Insert Table 1 about here ---

Our dependent variable is *Total Factor Productivity (TFP).* According to Porter and Linde (1995) productivity is the best measure of competitiveness because "competitiveness at the industry level arises from superior productivity, either in terms of lower costs than rivals or the ability to offer products with superior value and justify a premium price" (pp. 97-98). We estimated TFP using Levinsohn and Petrin's (2003) method. This method requires an output and three types of inputs (intermediate input, fixed capital and labour input). We used firms' accounting information from SABI to account for those inputs. Sales proxied output. Operating expenses were used as intermediate inputs, the book value of fixed assets measured fixed capital, and labor expenses measure labour input.

Our independent variable is Global value chain (GVC) breadth, depicted as the number of countries with production facilities. According to Benito *et al*. (2019) "the GVC approach provides a conceptual framework to describe, understand, and manage the increasingly disaggregated and geographically dispersed value chains" (p. 1415). Within this framework, the breadth of a firm's GVC is measured by the number of foreign countries in which the firm has at least one production subsidiary (Jankowska and Götz, 2017). This variable provides a good indication of the participation of firms in Global Value Chains. In the survey, respondents provide information on the number of countries in which they have a production facility. As can be observed in Table 2, almost three quarters of the firms (73.7%) perform all their production on the home market. Among the rest of firms, a majority have production facilities in 1 to 5 countries (22.3%). Only 17 firms (4%) have more than 6 production facilities abroad, 5 (1.2%) of them reaching 50 countries or more.

--- Insert Table 2 about here ---

Our moderating variable is *Industry 4.0*. This binary variable takes the value '1' when the firm uses 'virtual or cloud data storage' and 'computational intelligence and / or computational (digital) analytical tools to support decision-making', items that were introduced in the survey as separate questions. In total, 164 firms gave positive responses to those questions (38.5%) and can be classified as having Industry 4.0 capabilities.

The study contains a number of control variables. Firm size is operationalized with the *number of employees*. According to Table 2, the sample contains medium and large enterprises. The class size which is most represented is the one between 50 and 149 employees (55.2%). Roughly, a fifth of the firms are large as they employ more than 250 workers (20.8%). Other control variables are *firm age,* which measures the difference between the current year and foundation year, and *B2B* that measures the type of client. This binary variable takes the value '1' when the main client of the firm is another firm and '0' when the firm sells to end consumers.

Finally, the present study controls for industry and regional fixed effects. By design the study contains three manufacturing industries with NAICS codes 31, 32 and 33. These codes include industries such as food, beverage, and textile processing (NAICS 31); non-mineral manufacturing including wood, petroleum, plastics and chemical processes, and the pharmaceutical industry (NAICS 32); and mineral manufacturing, including the construction of hardware, vehicles, machines, turbines, and engines (NAICS 33). The study also controls for regional factors. In particular, we consider Spanish Autonomous Communities. Figure 2 maps the average value of the independent and moderation variables by region. The results are consistent with previous research that indicates Madrid and the Basque Country as Spanish leading-edge regions (Gomes *et al*., 2019; Gonzalez-Pernia *et al*., 2012).

--- Insert Figure 2 about here ---

3.3. Relevant subsamples

This study considers two relevant sub-samples characterized by the moderating variable, i.e. differentiating whether the companies possess Industry 4.0 capabilities or not. In order to describe the differences across these two samples, Table 3 compares mean values through a t-test for a number of relevant variables. The results of this descriptive exercise show that firms with Industry 4.0 are significantly larger (292 vs. 200 employees), more productive (1.74 vs. 1.71), operate in more countries (4.20 vs. 0.68) and more likely to have other businesses as the main client (0.76 vs. 0.66) than firms with traditional manufacturing. All these differences are significant at 5% (p-value <0.05). Interestingly, there are no significant differences across these groups in terms of firm age (46.8 years in both groups) and industry composition. The differences identified are significant, suggesting that samples should be analyzed separately (see Cassiman and Golovko, 2011; Gomes *et al*., 2018). Separating the analysis in these samples enables to test whether new technologies allow managing more complex global production systems, e.g. production facilities in multiple countries.

--- Insert Table 3 about here ---

3.4. Empirical design

Drawing on the empirical work of García-García *et al*. (2017) and Chen *et al*. (2018) who measured an inverted u-shaped (curvilinear) relationship between two constructs by employing ordinary least squares (OLS), we estimate the model in the following form:

$$TFP_i = \beta_0 + \beta_1 \#countries_i + \beta_2 \#countries_i^2 + \Omega_i + \gamma_s + \gamma_r + \varepsilon_i \quad (1)$$

Where the subscript *i* refers to the firm, TFP_i is the dependent variable, #countries is the independent variable, Ω_i is a vector of control variables that include firm size, firm age, and B2B, γ_s are sector fixed effects, γ_r are regional fixed effects, and, ε_i is the error term.

The inverse U-shape hypothesis will be confirmed if parameter β_1 is positive and significant (β_1 >0) and parameter β_2 is negative and significant (β_2 <0). By using differential calculus and the ceteris paribus condition, i.e. all other explanatory variables remain constant, it is possible to use parameters β_1 and β_2 to compute the number of countries that maximize predicted TFP (denoted with μ).

$$\frac{\partial TFP}{\partial \#countries} = \beta_1 + 2\beta_2 \#countries = 0 \qquad (2)$$

From equation (2) we can easily derive that the optimal number of countries that maximize predicted TFP is $\mu = -\beta_1 / 2\beta_2$. Hypothesis 2 suggests that by using Industry 4.0 technologies the number of countries that maximize firm productivity will be increased. This means that Hypothesis 2 will be supported if $\mu_{Industy\ 4.0} > \mu_{traditional}$.

4. Findings

Table 4 estimates Equation 1 for the full sample and the two relevant subsamples of this study, i.e. traditional manufacturing and Industry 4.0. The models have a good explanatory capacity as R^2 ranges between 0.21 and 0.26. In all models, β_1 is positive and β_2 is negative ($\beta_1 > 0$; $\beta_2 < 0$). The parameters are statistically significant at 5% in the full sample ($P < 0.05$), and statistically significant at 10% in the subsamples ($P < 0.1$). This result supports Hypothesis 1.

--- Insert Table 4 about here ---

The parameter μ equals 11 for the traditional manufacturing sample and 131 for the Industry 4.0 sample. This result largely supports Hypothesis 2 which states that firms with Industry 4.0 technologies can manage very large and complex global production systems. More specifically, Industry 4.0 firms can manage twelve times more production facilities than traditional manufacturing firms do.

Figure 3 explores the quadratic relationship between number of countries with production facilities and TFP for the two subsamples. This graphical analysis shows the difference in scale in this quadratic effect and the subsequent optimal number of global production facilities. In order to analyze this difference in scale we display two types of diagrams that we refer to as Zoom in and Zoom out graphs. Zoom in graphs analyze the relationship between number of countries with production facilities and TFP when we cap the number of GVC facilities at 20. The Zoom in graph shows the hypothesized inverse U-shape for traditional manufacturing firms (with the maximum at μ = 11), but for this range of GVC breadth the relationship seems positive and linear for Industry 4.0 firms. Zoom out graphs analyze the relationship between the number of countries with production facilities and TFP when the number of GVC facilities is capped at 200. The Zoom out graph shows the hypothesized inverse U-shape for Industry 4.0 firms (with the maximum at $\mu = 131$), but for this range of countries the relationship seems negative and quadratic for traditional manufacturing firms.

--- Insert Figure 3 about here ---

We consider that our graphical analysis indicates that technological change brought about by Industry 4.0 technologies has allowed companies to evaluate their international production strategy from a very different lens. Being able to share relevant information and acquire new knowledge in real time from multiple production facilities that might be located geographically distant (thousands of kilometres apart) provide important benefits (Chen, 2020). It potentially allows reducing coordination costs associated to decentralization of operations, eases knowledge access stimulating learning and creativity, as well as allows managing wider GVC breadth with globally spread value creation actors (Adenfelt, 2010; Strange and Zucchella, 2017).

5. Discussion and conclusion

Altogether, our results indicate that the adoption of Industry 4.0 technologies widens GVC breadth, and thus knowledge access sources, and performance configurations. In this regard, our study reveals that organizations adopting traditional manufacturing systems reach their productivity peak when implicating in GVC relationships of 11 linkages. Conversely, those organizations operating under the Industry 4.0 technologies reach their productivity optimum when becoming involved in GVC relationships of 131 linkages, which is twelve times more breadth. Our findings contribute to the IB literature, shedding light on the role of Industry 4.0 technologies in streamlining knowledge access/transfer and coordination within GVC settings with productivity implications (Alacer *et al*., 2016), and in doing so, responds to calls to widely assess the capacity of digital business models in raising firm's competitive advantage (Vendrell-Herrero *et al*., 2018). Our findings have a number of important theoretical and managerial implications for researchers and practitioners.

5.1 Theoretical implications

External knowledge access has largely been connected to productivity and profitability in international production research (Van Beers and Zand, 2014; Criscuolo and Timmis, 2017). In fact, even when they may be subject to diminishing returns, knowledge resources are always associated to a learning curve which, in general, results in positive gains (Asimakopoulos *et al*., 2020). On this point, we argue that the coordination costs of transnational linkages can outweigh the value of external knowledge access and lead to decreasing returns. A theoretical prediction confirmed by our empirical results that demonstrate that such a relationship follows an inverted U-shaped pattern. Accordingly, we claim that in GVC contexts knowledge resources may be associated to negative outcomes due to coordination diseconomies (Meyer *et al*., 2011).

Inter-firm knowledge transfer research, particularly in the context of GVCs, must address the transformative effect of Industry 4.0 technologies in terms of knowledge acquisition, assimilation, and dissemination (Chen, 2019). Close attention should be specifically paid to the absorptive capacity embedded in Industry 4.0 technological advances for facilitating timely transfer and interpretation of information e.g. via interactive data visualization. And by means of sensors, RFID, and actuators that gather and transfer information while monitoring all the different steps of the manufacturing process in real time (Haddud *et al*., 2017; Ghadge *et al*., 2020). Altogether, these technological capabilities not only speed up the learning processes, increase the pool of knowledge, and nurture creativity among GVC linkages, but also enable a close integration of spatially distant value chain links (de Vasconcellos *et al*., 2019). This is a result consistent with recent empirical evidence that demonstrates that decentralization is ultimately connected with the adoption of Industry 4.0 technologies in the value chain (Vendrell-Herrero *et al.*, 2021a).

Technological advancements have been connected in literature with reshoring or centralization strategies aimed at revitalizing manufacturing and increasing employment in the domestic market (Martin, 2018; James, 2018). Our results do not invalidate their potential for reshoring, but strongly suggest that Industry 4.0 technologies should stimulate, rather than constrain the decentralization of production globally. In this regard, reshoring might diminish the opportunities to obtain performance gains from external knowledge sources, which nowadays are crucial to achieving sustainable competitive advantage (Wang *et al*., 2019; Saliola and Zanfei, 2009).

5.2 Managerial implications

The findings of this study reveal that companies which adopt Industry 4.0 technologies are better prepared to engage in more complex and geographically distributed value chains than companies adopting traditional manufacturing systems. This is essentially due to Industry 4.0's technological advances having the potential to improve communication mechanisms and diminish coordination complexities between value chain links in global production operations (Szalavetz, 2019). Thus, the improved communication capacity simplifies information sharing and facilitates access to valuable knowledge from all the participants across the value chain (Strange and Zucchella, 2017). This process promotes intra/inter organizational learning and creativity, but also provides manufacturers with a pool of knowledge to make more informed decisions concerning whether, when, and how to adjust value chain processes (Vendrell-Herrero *et al*., 2021b). Hence, a key implication of our work is that, although Industry 4.0 technologies alone do not solve complexities and disruptions affecting world trade logistics (e.g. Covid-19 outbreak or the Suez Canal blockade), they do enable more agile decision-making processes and value chain adjustments to handle adverse and unexpected global events.

Furthermore, this research contributes to manufacturers' decision-making on whether to centralize or decentralize value chain activities. Based on our results, companies adopting traditional manufacturing systems are restricted to a narrower GVC breadth, whereas companies adopting Industry 4.0 technologies are able to manage a wider GVC breadth. Accordingly, we recommend production managers, particularly of medium-and large-sized enterprises (MLEs), to take into account the potential of Industry 4.0 technologies not only within individual functions and operational tasks, but also in the configuration of GVC networks.

5.3 Limitations and directions for further research

This article is subject to empirical limitations that open the door for future research. Primarily, it should be noted that due to the nature of representativeness of the Spanish economy in the form of medium-sized manufacturing companies (roughly 80% of the sample), it is plausible that a certain bias may occur towards companies that do not participate in global value chains. For instance, in our sample only 26% of surveyed firms have production facilities abroad. Future research should corroborate the results found in a sample of large and multinational companies (MNCs). Such an analysis should confirm that the results obtained in this study are transferable to highly internationalized environments.

In addition to this, the study uses a cross-sectional sample of data. Future studies should apply a longitudinal design to gain better understanding of the gradual rise in productivity as the company increases production abroad. Likewise, in this study we cannot directly observe how the external knowledge obtained abroad stimulates creativity and increases productivity. Future research drawing on qualitative methods should analyze these processes in detail.

Furthermore, this study does not assess how technology-enabled information is integrated and shared among GVC links. Further studies should explore interoperability issues of technologies operating under the Industry 4.0 paradigm in transnational inter-firm linkages, particularly how these technologies can be dynamically integrated in decentralized GVCs. Ultimately, an important avenue for future research would be to develop a more comprehensive measurement of Industry 4.0 technologies in manufacturing settings, one comprising requirements, developmental stages and outcomes. This will provide insights for companies on how to implement Industry 4.0 in value chains successfully. That being said, we hope this study may guide academics and managers to move forward in the understanding and implementation of Industry 4.0 technologies in value chain domains and international business (IB).

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Figure 1: Proposed framework for GVC, Industry 4.0, and firm productivity

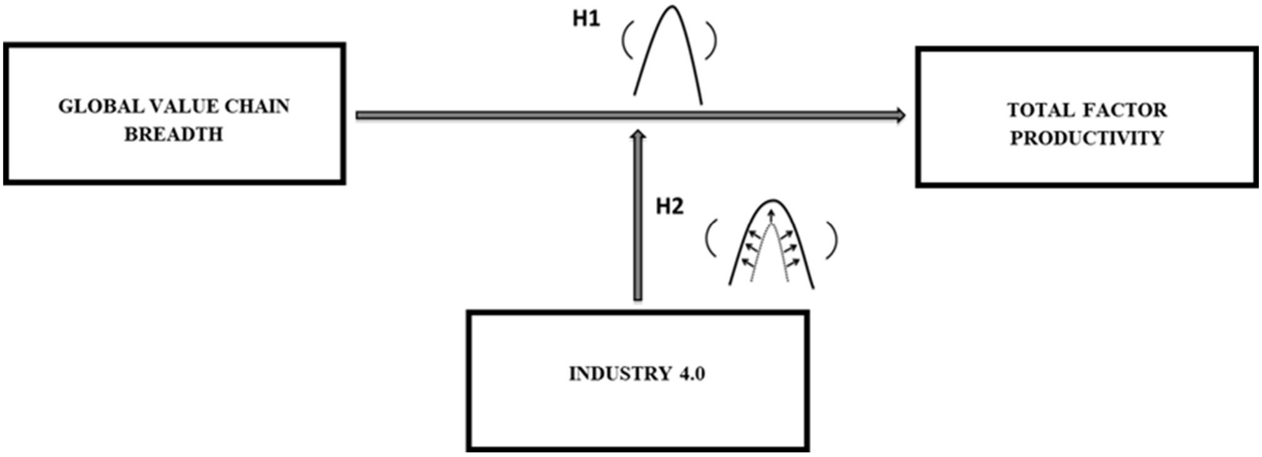

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Figure 2: Regional distribution of participation in GVC and adoption of Industry 4.0

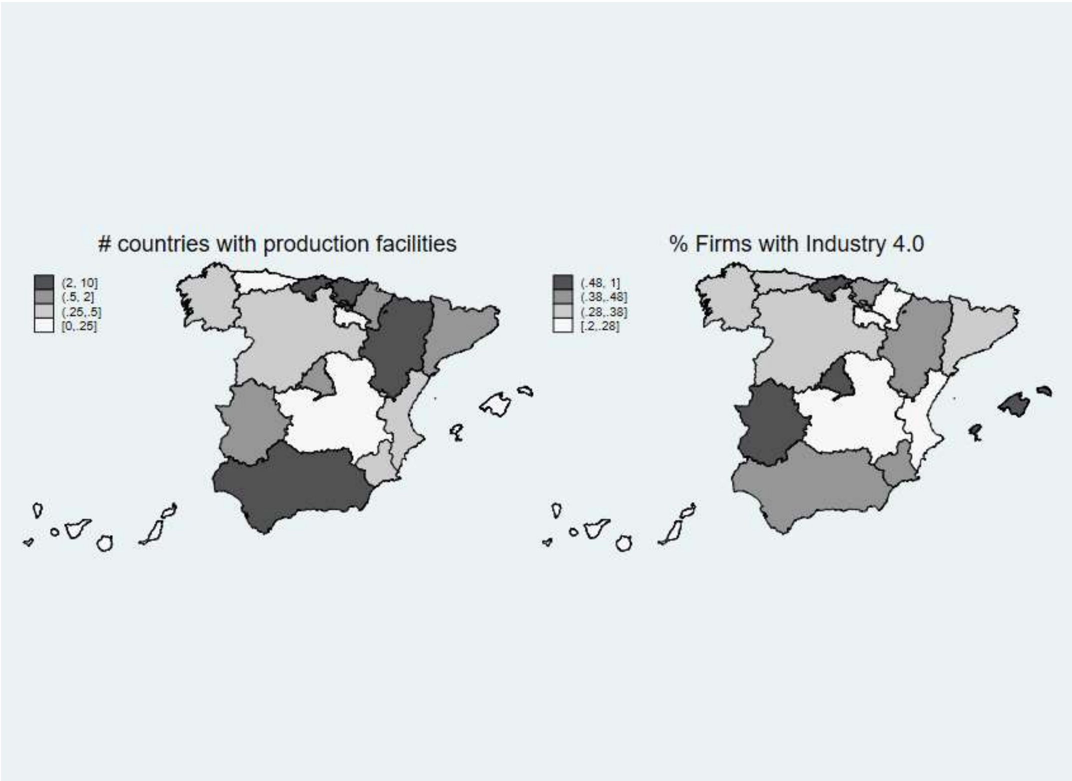

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Figure 3: Graphical analysis of the relevant relations

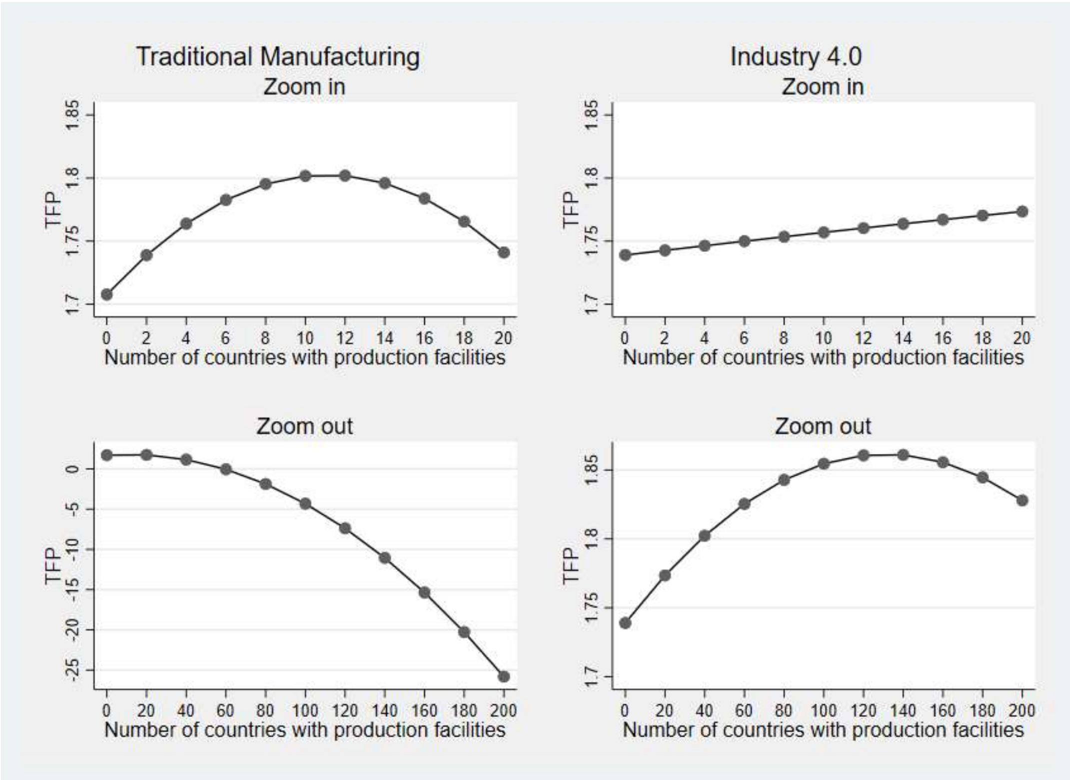

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Table 1: Measures description, data source and operationalization

Measure	Data Source	Operationalization	References
Dependent variable Total Factor Productivity (TFP)	**SABI database** Multidimensional measure of productivity that focuses on one output (Q = sales) and multiple inputs (L = labour expenses; IK = intermediate inputs measured as operating expenses; FK = fixed capital measured with book value of fixed assets).	Output and inputs are as per the equation: $Q = A*f(L, IK, FK)$ (1) Where parameter A is the TFP as it can be expressed as the ratio between output and production function $TFP = A = Q/ f(L, IK, FK)$ (2) We assume that function *f* follows a Cobb-Douglas functional form, so we can write equation (1) in the following way $Q = A*L^{\beta1}*IK^{\beta2}*FK^{\beta3}$ (3) We estimate Equation (3) by taking logarithms in both sides. Equation (4) enables an estimation of TFP $Ln(Q) = LnA + \beta_1 LnL + \beta_2 LnIK + \beta_3 LnFK + \varepsilon$ (4) The literature is rich in adjustments for this parameter. We followed the Levinsohn and Petrin (2003) approach for that purpose.	Saito and Gopinath (2011), Petrin and Levinsohn (2012), Ackerberg *et al.* (2015), Albulescu *et al.* (2021), Levinsohn and Petrin (2003)
Independent variable Global value chain (GVC) breadth	**SURVEY (purpose-built)** Number of countries with production facilities	This variable is based on the following question "*If the firm is engaged in foreign production, indicate the number of countries to which it has moved part of its production*" (Numeric) 73.7% of firms did not engage in foreign production. The rest of firms operate production facilities in 1to 140 countries.	Mihalache *et al.* (2012), Benito *et al.* (2019), Kano *et al.* (2020), Lafuente *et al.* (2021)
Moderating variable Industry 4.0	**SURVEY (purpose-built)** Production facilities with real time data and computational capabilities	Binary variable that takes the value 1 if manager responds positively to the following two questions. *Does the firm use virtual information storage or store information on the cloud?* (Y/N) *Does the firm use computational intelligence and/or computational (digital) analytics tools to support decision-making?* (Y/N)	Lin *et al.* (2019), Tortorella *et al.* (2019), Tortorella *et al.* (2021), Wang and Hsu (2021)

		38.50% of firms do have production facilities with Industry 4.0 capabilities.	

Table 2: Distribution of observations in terms of GVC participation and size

GVC class		**Size class**	
Number of countries		***Number of employees***	
0	314	1-49	0
	73.7%		*0.0%*
1-5	95	50-149	235
	22.3%		*55.2%*
6-10	7	150-249	102
	1.6%		*23.9%*
11-49	5	250-999	79
	1.2%		*18.5%*
50+	5	1000+	10
	1.2%		*2.3%*
Total	**426**		**426**

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Table 3: Comparing mean values of key variables by type of manufacturing

	Traditional Manufacturing	**Industry 4.0**	**T-test**
Observations	262	164	--
(%)	*61.5%*	*38.5%*	--
TFP	1.714	1.742	0.035
# countries	0.68	4.20	0.015
# Employees	200.3	292.1	0.049
Firm age	46.87	46.84	0.992
B2B	0.763	0.676	0.050
NAICS-31	0.282	0.317	0.447
NAICS-32	0.305	0.250	0.219
NAICS-33	0.412	0.433	0.674

Table 4: Number of countries with production facilities and firm productivity

	(1) Full sample	(2) Traditional manufacturing	(3) Industry 4.0
Number of countries	0.002**	0.017**	0.002*
	(0.001)	(0.007)	(0.001)
	0.014	0.018	0.061
Number of countries squared	-0.000**	-0.001*	-0.000*
	(0.000)	(0.000)	(0.000)
	0.026	0.080	0.079
Employees/100	0.010***	0.010***	0.010***
	(0.003)	(0.003)	(0.003)
	0.000	0.003	0.001
B2B	0.005	0.012	-0.002
	(0.014)	(0.020)	(0.021)
	0.716	0.542	0.943
Firm age	0.060***	0.064**	0.066**
	(0.018)	(0.025)	(0.028)
	0.001	0.012	0.019
Constant	1.652***	1.628***	1.677***
	(0.034)	(0.046)	(0.052)
	0.000	0.000	0.000
Observations	426	262	164
R-squared	0.216	0.222	0.263
Regional FE	YES	YES	YES
Industry FE	YES	YES	YES
Optimal # countries (μ)	133.05	11.08	131.20

Dependent variable: Total Factor Productivity (TFP)
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1