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Industry 4.0 and potential for reshoring: A typology of technology profiles of manufacturing firms☆

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A R T I C L E I N F O

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A B S T R A C T

The paper analyses the trend towards reshoring processes in the field of manufacturing industry as a result of the massive digitisation of the technical solutions used by most product fields. The paper analyses the trend towards reshoring processes in the new productive scenario of industry 4.0 posed by the manufacturing industry because of the overall application of ICT and other technologies in their product fields.

The incorporation of Industry 4.0 technologies (I 4.0 T) and the resulting digitalisation raises needs for technology adaptation in production plants that have strong territorial effects derived from the technological constraints linked to the adaptation process itself and that result, in many cases, in reshoring.

Our analytical proposal takes a logical-formal point of view based on the cognitive composition of the technical solutions used by manufacturing industry, and draws up a typology of technology profiles to help determine the potential for reshoring among offshored plants and the difficulties that the process may entail.

The results enable us to identify a growing role for reshoring processes, distinguishing different degrees of intensity depending on the characteristics of the technological scenario in which each plant is located, with the technological resources offered by its local setting playing a fundamental role.

1. Introduction

In recent years there has been growing interest in both political debate and economic literature in analysing the meaning and scope of reshoring processes (Barbieri et al., 2020; Raza et al., 2021; Boffelli and Johansson, 2020; Dachs et al., 2019a; Dikler, 2021; De Backer et al., 2016; Młody and Stępień, 2020; Bolter and Robey, 2020; Dachs et al., 2019b; Engström et al., 2018; Johansson et al., 2019; Wan et al., 2019; Di Mauro et al., 2018; Wiesmann et al., 2017), understood as the bringing back to a company's country of origin of a production activity that it had previously offshored (Dikler, 2021; Hilletofth et al., 2019; Bolter and Robey, 2020).

All the data strongly confirm the intensity of this phenomenon in Europe[1] (Kinkel, 2014; De Backer et al., 2016; Kinkel et al., 2020; Somoza-Medina, 2022; Eurofound/European Commission, 2022) and, especially, in the United States (Dikler, 2021; Bolter and Robey, 2020), where the latest data provided by ReshoreNow (2021) indicate that the reshoring increased in 2020, with a total of 1484 more companies being involved and a record number of 109,000 jobs created, bringing the total jobs announced since 2010 to more than 1 million. Empirical evidence over the last ten years confirms that these processes are increasing (Raza et al., 2021; Dikler, 2021; Thomas Industrial Survey, 2020).

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[1] Kinkel (2014) estimated that around 400–700 German companies per year have backshored activities. De Backer et al. (2016) conclude that the data for Austria, Switzerland, Germany, Denmark, Spain, France, Hungary, Portugal, Netherlands, Sweden and Slovenia show that around 4% of firms in the survey sample had moved production activities back home.

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The first analytical tool for ordering the relevant elements and understanding the basic features of FDI was Dunning's eclectic paradigm (1979). More recently, economic literature has generated a large number of studies that explain how companies behave in locating production operations and in reshoring from various perspectives.

In the fields of operational management, strategic management, international business and the political economy, a large volume of literature has grown up which is focused on identifying the reasons or enabling factors underlying reshoring processes. Ancarani et al. (2015) group the numerous motivations for reshoring into homogeneous categories, such as cost-, quality- and risk-related. That literature covers both operational and institutional perspectives (Fratocchi et al., 2016; Srai and Ané, 2016) that help explain reshoring (Fratocchi et al., 2016).

The results show many different factors that help explain reshoring. The extent to which each of them explains the individual firms' behaviour varies depending on what offshore challenges the firm faces (Fratocchi et al., 2016; Srai and Ané, 2016; De Backer et al., 2016; Bolter and Robey, 2020; Eurofound, 2019a; Dachs et al., 2019a; Di Mauro et al., 2018; Barbieri et al., 2020; Reshoring Initiative, 2021) and on the attractiveness of the company's country of origin given the characteristics of the local ecosystem (Pegoraro et al., 2022). All of this without forgetting that an increasing number of national governments are enacting industrial policy to support firms' relocation strategies with incentives (Karatzas et al., 2022).

A very important element in explaining reshoring processes is the massive influx of ICTs into manufacturing industry, giving rise to what is known as Industry 4.0. The enormous capacity of ICT technologies to generate new, increasingly complex, applications with mutually complementary effects is causing a massive interconnection between production activities and shaping the competitive dynamics of virtually all manufacturing industry (Freeman and Perez, 2008; Bresnahan, 2010).

The incorporation of digitalisation into products and processes makes the cognitive composition of the technical solutions used more complex, raising needs for technological adaptation by companies that must be applied to all their production plants to remain competitive enough to ensure their continuity in the market. Adaptation is bound to have very powerful territorial effects because of the territorial constraints linked to the adaptation process itself. In many cases these territorial changes can mean the reshoring of activities to obtain the advantages that come with proximity to the company's technological resources and with a local setting of greater technological wealth.

The acknowledged importance of technology in generating territorial effects justifies the goal of our study, which is to analyse the meaning and scope of the incorporation of I 4.0 T into manufacturing industry in terms of reshoring. Our study leaves the usual perspective provided by the economic literature based on studies that explains reshoring based on the specific characteristics of the operations of each firm and seeks to help explain reshoring processes by addressing the link between Industry 4.0 and reshoring from a theoretical approach that seeks to build technological scenarios that can help explain behaviours in terms of reshoring.

Research has confirmed that Industry 4.0 is a factor conducive to reshoring (Fratocchi and Di Stefano, 2020), but the small number of studies conducted means that caution is required in drawing conclusions. On the other hand, this is an incentive to continue studying the matter in more depth. It must also be noted that the findings in the literature devoted to determining the reasons for reshoring indirectly support the link found, in that all the research conducted highlights the factors that accentuate its presence in the context of Industry 4.0.

With this in mind, the rest of the paper comprises four sections: Section 2 formulates the theoretical framework and Section 3 states the methodology of analysis applied in our study. Section 4 identifies the technology profiles that can be found in manufacturing industry and Section 5 analyses the reshoring possibilities identified in the different scenarios provided by the technology profiles established. The final section sums up the main conclusions of the paper.

2. Theoretical framework: industry 4.0 technologies and reshoring

It is widely admitted that there are links between Industry 4.0 and reshoring (Fratocchi and Di Stefano, 2020; Unterberger and Müller, 2021; Ancarani and Di Mauro, 2018; Ancarani et al., 2019; Bolter and Robey, 2020; De Backer et al., 2016; De Backer et al., 2018; Laplume et al., 2016; Dachs et al., 2019a; Stentoft and Rajkumar, 2020; Moradlou and Tate, 2018) and that the various technologies involved in Industry 4.0 may have different effects on re-shoring (Ancarani and Di Mauro, 2018; Raza et al., 2021; Fratocchi and Di Stefano, 2020).

In industries with higher labour costs, locating to developed countries has only recently become economically viable because of the increasing degree of process automation (Arlbjørn and Mikkelsen, 2014). Of the various technologies involved in Industry 4.0, robotics is best suited to customised manufacturing, benefiting industries where the market demand and consumer preferences change rapidly. In such industries, robots enable firms to bring new products to the market far more quickly than with offshoring, which often involves distant countries where suppliers do not always produce to the correct specifications, resulting in quality problems and long lead times (De Backer et al., 2018). In a study conducted in 2016 and 2017 on 270 Danish firms with more than 25 employees concerning practices associated with Industry 4.0, Stentoft et al. (2017) conclude that automation both discourages offshoring and encourages re-shoring.

However, in a study that uses a large database of schemes for reshoring to the USA and Europe, Ancarani and Di Mauro (2018) conclude that robotics are not a necessary ingredient for re-shoring and that most re-shored firms do not adopt robotics and labour saving technologies. Robotics is used more by cost-oriented firms, given that the gap in labour costs with respect to producing abroad carries more weight for them. In any event, Raza et al. (2021) state that automation can also be conducive to offshoring, as it helps to strengthen the productivity of production processes in emerging economies.

Big data analysis and digitalisation increase capacity for coordinating operations remotely, which may make re-locating to low-cost countries an attractive prospect (Ancarani and Di Mauro, 2018), but additive manufacturing technologies have a positive impact on decisions to re-shore, pushing value chains to become more local and closer to end-users (Moradlou and Tate, 2018; Laplume et al., 2016; Raza et al., 2021), especially in the case of re-shoring decisions made on quality grounds (Ancarani and Di Mauro, 2018). Specifically, Moradlou and Tate (2018) identify 6 potential areas where additive manufacturing may impact the supply chains of companies, making them more receptive to re-shoring: shorter lead times, better response capabilities in terms of product and market changes, lower transport costs, fewer communication errors with suppliers, more customisation options and lower product inventories in stock. Fratocchi (2017) on his side, confirmed through 8 case studies that the adoption of additive manufacturing technologies contributed to the firm's decision to reshore. Likewise, Fratocchi and Di Stefano (2020) concluded that both automation and additive manufacturing technologies are likely to support different types of reshoring decisions.

Various authors have suggested that more research is needed into what types of operation may be good candidates for re-shoring, and whether a characterisation by industries can be drawn up (Fratocchi et al., 2014) taking into account variables such as company size and the technology-intensity of each industry (Fratocchi et al., 2014; Stentoft et al., 2017). The technology dynamic is precisely the approach followed by this paper.

2.1. *Theoretical approach for the study*

Our theoretical approach is based on a vision of the technology dynamic as an evolutionary process in the field of knowledge that supports the technical solution that results in actual products/processes. That vision highlights the specific nature of the technology problems faced in each product field and serves as a reference point for analysing territorial problems associated with technology creation/adaptation arising from the influx of I 4.0 T and mainly ICTs in the technical solutions used by manufacturing industry.

To carry out this adaptation and bridge the cognitive gap, plants need to call on a) the resources that make up the technological potential of the company; and b) the technological resources that can be provided by the setting in which they are located. Bearing this in mind, reshoring is an option that provides location advantages over other alternative destinations, insofar as it enables more extensive, more efficient to be made use of the resources that make up a firm's technology potential, which are located in the framework of its central laboratories, due to proximity constraints.

In line with the aforesaid references, we draw up a taxonomy of technology profiles found in manufacturing industry, based on the cognitive dimensions observed in the technical solutions that they use which are likely to entail proximity constraints. Determining how closely the various production activities match the profiles found helps to draw up, from a formal logic viewpoint, a typology of technology scenarios based on the problems of technology adaptation as a consequence of digitalisation in the production plants that a company has established abroad. This serves as a basis for explaining reshoring for technological reasons. These scenarios are constructed taking into account the technology profile of each plant, the technology potential of the company to which it belongs and the technology potential of the setting in which it is located.

2.1.1. Technological dynamics and evolutionary specificity

From the perspective offered by the evolutionary approach, a technical solution that enables a product to be produced based on a process is understood to involve a unique cognitive combination, and in that sense a defining singular field of knowledge that evolves, striving to improve its performance according to a dynamic of cumulative evolution, in which learning processes play a substantial role (Dosi, 1982; Foray, 2000; Dosi and Nelson, 2011; Lundvall, 1992; Edquist, 1997). A technical solution is nothing more than the result of a synthesis of knowledge originating from different fields through which a process is formalised. This, in turn, leads to the attainment of a technical goal in terms of product design (Ruttan, 2001; Foray, 2000; Utterback, 2001; Niosi, 2000).

Based on this argument, we consider two references of interest for our analytical purposes: the first is the cognitive specificity of each technical trajectory, which means that the demands of technology adaptation will be unique and different in each technical solution. The second recognises the enormous technological heterogeneity of manufacturing industry and the need to narrow the focus of analysis of the effects to the circumstances of each industry. This analytical approach has made a space for itself in economic literature (Breschi and Malerba, 1997; Breschi et al., 2000; Dosi et al., 2006; Marsili and Verspagen, 2002; Bilbao et al., 2021). It enables the likelihood of reshoring of each industry to be identified according to its degree of similarity with the profiles established.

2.1.2. Cognitive distance and technology adaptation

The incorporation of I 4.0 T poses a problem of technology adaptation in each production plant that is related to the cognitive distance between the technical solution currently used and that which the plant must use after the efficient incorporation of ICTs and other technologies in that technical solution.

To carry out this adaptation and bridge the cognitive gap, the plant relies on the joint work of: (a) the resources that make up the technological potential of the company of which it forms part; and (b) the technological resources that can be provided by the setting in which the plant is located.

It is important to note that for any adaptation process to be effective, the actors involved must have prior skills in the technologies to be implemented (Nooteboom, 1999: 795). Only then is it feasible to absorb the knowledge needed to make the desired adaptation possible (Penner-Hahn and Shaver, 2005). A very weak internal potential and a very weak context will both cause a technology adaptation process to fail.

The specificity of each technical trajectory raises an adaptation problem that is unique to each technical solution and underlines the importance of the company's technological potential, which brings together the knowledge that it has accumulated in the fields of knowledge that define the technical solutions that it uses, usually located at its central laboratories, to carry them out in an efficient way.

On the other hand, the technological resources of the local setting in which the plant is located are also fundamental in making the adaptation process operational and ensuring that the results are competitive, for three main reasons:

Firstly, because the penetration I 4.0 T in the product fields of manufacturing industry involves incorporating new, science-based knowledge with a high level of novelty (Scherngell and Barber, 2011) and thus a large tacit component. This entails major proximity constraints for the agents who must work together to bring about effective knowledge transfer (Davids and Frenken, 2018; Carrincazeaux, 2009; Asheim et al., 2007; Torre, 2008; Mattes, 2012). This is a fundamental factor in view of the need of firms to resort to their external setting in order to incorporate those applications into their products and processes.

Secondly, because of uncertainty about future technological needs that may lead to changing cognitive and resource requirements over time. Companies can protect themselves from this uncertainty about future needs by locating in high-potential areas that may be able to meet them. This is a highly important point given the great scope of I 4.0 T for generating new solutions in all directions, and doing so at a high rate of change in supply, which, in turn, means that the developments generated rapidly grow obsolete. This is a very powerful argument for explaining the location of production activities (Castellacci, 2008), if it is taken into account that the process is far from over and there are still enormous development possibilities offered by the fields of artificial intelligence and quantum computing.

Thirdly, because efficient plant operation calls for human resources with the necessary qualifications (Frey and Osborne, 2013 and 2017; Autor, 2015) and access to technical assistance services, training services and technological services that can make plants effective. The qualifications of human resources play a key role as a location determinant (Eurofound, 2019b; Strange and Zucchella, 2018; Boffelli and Johansson, 2020). Factoring in the ability to develop learning and adapt to the changes proposed by technology dynamics (closely related to the worker's cognitive mastery of the product/process that he/she is handling), the fact that digitalisation requires other transversal skills (such as the ability to work with data and make decisions based on it, the ability to solve complex problems, the ability to work in a team, creativity and analytical thinking (Manyika et al., 2017), location can be assumed to play a key role in offering these resources.

3. Methodology

Based on the importance we attach to the technological element in order to generate territorial effects, our analysis focuses on the meaning and scope of Industry 4.0 as a productive framework that enhances reshoring processes. The incorporation of ICT applications that materialise Industry 4.0 poses a problem of technological adaptation that will be specific to each production plant, derived from the cognitive composition of the technical solutions it handles, and which must be solved by taking into account a) the resources that make up the technological potential of the company, and b) the technological resources that can be provided by the context in which the plant is located.

The reshoring alternative can provide location advantages over other alternative destinations, to the extent that it allows a more extensive and efficient use of the resources that make up both the technological potential of the firm and the technological context in which it is located.

From a logical-formal point of view and based on the cognitive composition of the technical solutions that Industry 4.0 handles, we construct technological profiles that identify the cognitive demands posed by the process of technological adaptation of the plant to Industry 4.0. Based on the established profiles, and taking into account the technological potential of both the company of which it forms part and the context in which it is located, we will be able to build technological scenarios. From these scenarios, we can determine the potentialities and difficulties that may affect plants located offshore in order to carry out reshoring processes.

We set out to construct a typology of behaviours based on two reference variables that we consider fundamental for establishing the profiles sought:

1. A typology of companies according to the positions in the value chain of the products that they manufacture. We use the three types of agents considered in the Industrial Economy to describe the value chain in its organisational models. This classification is especially effective for our purposes because it enables us to break down the value chain in a way that covers all manufacturing production possibilities. We distinguish between end product manufacturers, system manufacturers and part/component manufacturers.
2. The cognitive composition of the technical solutions used for manufacturing. The relevant cognitive dimensions to explain technological adaptation problems would be the following:

1. Degree of novelty of the knowledge bases supporting products and processes.
2. Degree of complexity of the knowledge support of the technical solutions used by a production activity.
3. Characteristics of the organisational model governing the value chain of which a production activity forms part.

In this way, we would be opening a line of theoretical reflection on the phenomenon of reshoring, based on the case literature, in order to contrast the scope of our formal results.

4. Typology of technology profiles in manufacturing industry

We set out to construct a typology of behaviours based on two reference variables that we consider fundamental for establishing the profiles sought: (1) a typology of companies according to the positions in the value chain of the products that they manufacture; and (2) the cognitive composition of the technical solutions used for manufacturing.

4.1. Typology of companies according to the characteristics of the product that they manufacture

We use the three types of agent considered in the automotive industry to describe the value chain in its organisational models ("lean manufacturing") (Aláez et al., 2008; Boyer and Freyssenet, 2000; Freyssenet, 2009). This classification is especially effective for our purposes because, firstly, it enables us to break down the value chain in a way that covers all manufacturing production possibilities. Secondly, it enables us to draw up a typology of technology profiles among manufacturers that covers two basic elements in explaining the territorial aspects of the problems of technology adaptation faced by production operations: a) the cognitive composition of the technical solutions used; and b) the location of each production plant in the value chain in which it operates. This is a highly useful reference point for the purposes of our analysis, as it helps us to explain reshoring processes based on the technology problems identified.

We distinguish between end product manufacturers, system manufacturers and part/component manufacturers. All three types can give rise to multinational companies with plants in different locations and thus be subject to reshoring.

4.1.1. End product manufacturers

This is a very broad group, which includes a wide variety of industrial activities, ranging from large manufacturing companies such as the automotive and aeronautics industries to those that manufacture consumer products, footwear, textiles, household goods, etc. and the whole wide range of electronic products. This is the most diverse group for which we identify all the cognitive possibilities (technology problems).

4.1.2. System manufacturers

System manufacturers obtain a specific design through a process solution. That design meets certain performance requirements for incorporation into the end product of which it forms part. Highly systemic products such as automobiles feature various systems: braking system, engine, transmission, etc. They are end products in themselves, as they seek to meet certain measurable performance requirements, subject to the need to converge with the rest of the systems in the end product. The system, in turn, can be the result of a value chain built up based on contributions from different companies that provide the components that make it up.

4.1.3. Part/component manufacturers

Part/component manufacturers work to order from other manufacturers, producing parts that, in themselves, lack identity in terms of product/performance. That identity is acquired through assembly with other parts into the system or end product of which they are a part. A change in the specifications of a part is meaningless unless it is in response to a redesign in the assembly to which it belongs. Its technical evolution is centred on the search for greater efficiency by improving processes. The production possibilities are vast, from the manufacture of screws to door handles or zippers for clothing.

4.2. The cognitive composition of technical solutions

The most relevant cognitive dimensions to explain the problems of technological adaptation posed by the incorporation of the I 4.0 T would be:

1. Degree of novelty of the knowledge bases supporting products and processes.
2. Degree of complexity of the knowledge support of the technical solutions used by a production activity: technological complexity and combinatorial complexity.
3. Characteristics of the organisational model governing the value chain of which a production activity forms part. This affects value chains that are segmented.

4.2.1. Degree of novelty of the knowledge bases supporting products and processes

This variable is highly relevant because it describes the trend over time of the cognitive composition of the technical solutions that make up a product field (Utterback, 2001; Foray, 2009; Czarnitzki and Thorwarth, 2012; Schoenmakers and Duysters, 2010; Foray and Lissoni, 2011; Ruttan, 2001; Markard, 2020).

The technology dynamics in the early stages of the lifetime of a product field are marked by the prevalence of basic knowledge and instability in the composition of its technical solutions. This is a difficult stage to formalise (Niosi, 2000; Rotolo et al., 2015). The high productivity of R&D determines continuous improvement in designs and continual changes in processes that are constantly adapting to change (Garnsey and Heffernan, 2005; Himanen and Castells, 2006; Motoyama et al., 2011). Industry 4.0 thus could encourage re-shoring whenever bringing the value chain back together is important for developing products, creating prototypes, etc. In such cases, joint location of production and development may become a source of value creation (Ancarani and Di Mauro, 2018). Thus, Industry 4.0 could play a role in reshoring when companies aim to improve design and strengthen product-development linkages (Fratocchi and Di Stefano, 2020).

Production activity is led by companies with a high technology potential located in territories which also have a high technological potential, which must offer the high-tech resources necessary to participate in this dynamic of permanent change. "Degree of novelty" is a relevant variable insofar as it enables us to rule out the early stages of the lifetime of a product field as being susceptible to reshoring.

4.2.2. The degree of complexity of the supporting knowledge: technological complexity and combinatorial complexity

The technological complexity associated with a product field determines how prevalent scientific knowledge is in shaping the cognitive basis of its designs. The design of a product or process is said to be science-based if it is the result of practical applications obtained from the possibilities offered by knowledge formalised in scientific principles and theories (Freeman and Perez, 2008; Foray, 2000; Dosi and Nelson, 2011; Edquist and Hommen, 2008; Niosi, 2010). On the other hand, it is known that any technical solution is always the result of a convergence of knowledge from different fields that is used to materialise a product/process. It is a synthesis of knowledge which, in turn defines its own unique field of knowledge, and which has a degree of combinatorial complexity that quantifies the number of fields of knowledge involved in the synthesis (Carrincazeaux, 2009).

The entry of I 4.0 T into manufacturing product fields means the incorporation of new science-based knowledge belonging to technologies with a high degree of novelty (Scherngell and Barber, 2011). This generally increases both the technological and combinatorial complexity of their knowledge bases. Science-based knowledge is incorporated, at a great cognitive distance from that used in conventional processes; this requires a process of technology adaptation in the companies that carry it out, in which the setting where plants are located plays a fundamental role.

The scientific nature of knowledge requires an understanding of the scientific principles that explain the phenomena used in technical solutions, because this is essential to achieving efficient operation of the processes and responding effectively to operating problems and to the adaptations that will inevitably have to be made as a result of the technical evolution of the product/process. It should be noted that the ability to efficiently manage a process, and to develop learning and adapt to the changes proposed by its technological dynamics, is closely related to cognitive mastery of products/processes by workers. The degree of specificity of the knowledge incorporated increases with the combinatorial complexity of the technical solution, making adaptation more complex.

Therefore, a link between Industry 4.0, product innovation and reshoring could be stablished, as creating and reinforcing ecosystems can provide leverage for attracting manufacturing currently based offshore and providing a base for future technology development (Ancarani et al., 2019). A company's decision to relocate must be understood by linking it to the context of the destination determined by regional institutions and key players, policies and access to relevant technology and talent (Pegoraro et al., 2022). As recent studies show, apart from the search for brand recognition tied to country-of-origin effects, the need to connect to advanced innovation ecosystems characterise both backshoring from China and Chinese FDI initiatives to developed countries (Ancarani et al., 2021).

4.2.3. Characteristics of the organisational model describing the functioning of industries

The characteristics of the organisational model fundamentally affect production activities that are systemically articulated within segmented value chains. The value chain is understood as a network of relationships between different hierarchically linked companies, its operational efficiency is based on a body of knowledge developed through learning that takes place in the relational sphere (learning by interacting (Lundvall, 1992). This knowledge is essentially tacit and highly specific to each particular relationship, and is held by the plants involved in the relationships. From the viewpoint of analysing reshoring processes, we are interested in the relational sphere that affects collaboration between agents, which is concerned with the coordination of the flows of goods between the companies in the value chain. This could explain why some experiences show a positive relationship between the success of the reshoring strategy through Industry 4.0 and the preparation of the local ecosystem, so that the company is able to absorb the tacit knowledge of its local system (Pegoraro et al., 2022).

The level of exigency involved in the relations between the companies involved in the value chain varies widely. It may range from highly demanding approaches involving forms such as "lean production" (applied in the automotive sector to relationships between the final manufacturer and system manufacturers (Freyssenet, 2009; Frigant, 2007; Boyer and Freyssenet, 2000)) to less demanding approaches such as those that involve manufacturers of parts/components. Gereffi et al. (2005) and Gereffi and Lee (2012) provide a useful conceptual benchmark for measuring the cognitive scope of relational practices between collaborating firms.

The specificity of the knowledge created by relational learning through business collaboration makes it unique and distinct in each relationship, increases efficiency in the operation of the chain and conditions the competitive positions of the participating companies. To the extent that plants are the repository of this learning, those that develop a more intense relational component in their operations have a favourable argument for consolidating their position in the value chain in which they participate. When the enormous possibilities offered by new ICT developments to facilitate increasingly efficient logistics solutions (Chen et al., 2016; Rezk et al., 2016) are considered, the competitive importance of this knowledge for those plants working within the framework of demanding logistics relationships is easy to understand. It affects mainly the relationships between the final product manufacturer and the system manufacturer, especially if they work on the basis of technical solutions which are highly technologically complex.

4.3. A typology of business profiles

Applying the variables considered to the activities that make up manufacturing industry opens up a very wide range of combinatory possibilities in terms of technology profiles. The variable "company typology according to the characteristics of the product manufactured", which we use as a behavioural reference for businesses, enables us to significantly reduce the casuistry, making our study more operative.

The end manufacturer admits all cognitive alternatives except the one that combines high combinatorial complexity with low technological complexity. The possibility of a high number of knowledge fields coinciding in a single technical solution, all of them with low scientific content, must be discarded. A review of the actual situation of industry offers empirical support for this assumption.

The technical solutions used by systems manufacturers may have different levels of (science-based) technological complexity, but they can be assumed to have a low level of combinatorial complexity. Systems are manufactured in a segmented fashion where specialist production is used to enhance efficiency in the preparation of specific designs. A number of parts and components are used to set up a specific design (system) capable of attaining a specific technical goal, which is then converged with other components and systems to form part of the product made by the end manufacturer.

In cognitive terms, systems manufacturers can be expected to use technical solutions with low levels of combinatorial complexity (though their technological complexity may be high or low) because the segmented production method tends also to segment the cognitive composition of the end product in pursuit of greater efficiency.

The logic of productive segmentation will respond, essentially, to a logic of cognitive segmentation based on technical solutions of low combinatory complexity built, therefore, on the basis of a limited number of fields of knowledge, with the objective that the system manufacturer achieves high efficiency in its innovation activity. Cognitive segmentation will form part of the final manufacturer's organizational strategy that will take advantage of the improvements achieved by the systems manufacturer.

Even in those contexts where systems production is most complex, such as the automotive industry, the knowledge bases used to manufacture braking or transmission systems, for example, have low levels of combinatorial complexity, taking into account that the entire set of knowledge used by system manufacturers must be coherent in the final product. It is only when the vehicle *assembler* brings together all the systems into the final design that it handles cognitive bases with greater combinatorial and technological complexity. Even so, logistical requirements and cooperation with customers and suppliers play a substantial role in making systems work insofar as they form part of a value chain.

In the case of parts/component manufacturers, the cognitive possibilities are limited to technical solutions with low combinatorial and technological complexity. There are, of course, components with high technological complexity, but they correspond to highly novel product fields where production is not outsourced (or is outsourced to locations with a high technology potential that are not affected by reshoring). The case of components which become the repository of new applications as a result of digitalisation is quite different, and is considered as such in our analysis. For such components there is an increase in technological complexity which, logically, has territorial effects.

Fig. 1 summarises this typology of situations.

		End product manufacturers		System manufacturers		Part/component manufacturers	
		Combinatorial Complexity					
		High	Low	High	Low	High	Low
Technological Complexity	High	X	X		X		
	Low		X		X		X

Fig. 1. Typology of technology profiles
Source: Own work.

5. Scenarios for reshoring according to technology profiles

Based on the indicated analytical tools, we are in a position to identify the reference scenarios to estimate effects on the reshoring processes derived from the incorporation of the I 4.0 T:

5.1. *End product manufacturers*

This heading covers a very broad universe that includes many types of industrial production, ranging from large manufacturing industries such as the automotive, aeronautics and electronics industries to a wide range of consumer goods. It is the most complex group in which all the cognitive possibilities (technological problems) are identified. Some of its production processes lend themselves to segmentation and others do not.

5.1.1. *High combinatorial complexity and high technological complexity*

This heading covers the set of products with the greatest cognitive complexity, where an initial distinction can be drawn according to whether the processes used can be segmented. In segmentable product fields, such as the production of automobiles or aircraft, a strong externalisation of production can be expected in pursuit of greater efficiency in the systems that make up the end product, but it is the manufacturer that synthesises the technological behaviour of all the agents that intervene in production. In a systemic technology context, the end manufacturer is responsible for the synthesis and must therefore assume the leading role in terms of innovation for the whole fabric of production (Aláez et al., 1996). Note that in segmentable fields it makes little sense to internalise the production of systems, except for those that have a strategic value, because the output of the systems that make up the end product depends on an economic rationale that is not compatible with the plant's production volume. These are industries in which the characteristics of products/processes lend themselves to the large-scale entry of I 4.0 T (and mainly ICT applications) in both the individual systems used and the synthesis of all those systems in the end product.

On the other hand, the broad possibilities offered by the development of scientific knowledge in the search for new technological solutions has led to the appearance of non-segmentable technical solutions of high combinatorial complexity, which synthesise knowledge originating in very different fields to achieve increasingly sophisticated, efficient performance. The fields of biotechnology are a case in point (García Olmedo, 1998).

From a technological point of view, productive activities in these product fields, whether segmented or not, can be expected to be led by companies with a high technology potential and with central laboratories which are only viable in settings with a high technology potential. A fabric of production can be expected which has sufficient internal technology potential to incorporate the necessary I 4.0 T into its products and processes, but even so it will always be necessary to resort to the setting to adapt the composition of plants to new needs in terms of skilled labour, training, technology services, etc., associated with the operation of production plants under the new conditions. Insofar as the plants must also be located in settings with sufficient technology potential for the efficient operation of plants that already handle solutions of high combinatorial and technological complexity, they can be expected to be in a position to meet the new requirements in their current location. If the technology argument is supplemented by the argument that such plants require large investments with high disinvestment costs that would be an obstacle to plant mobility (Bilbao and Camino, 2008), it can be concluded that there will be very little pressure to reshore them.

In any case, these are the product fields where technology requirements are highest. Given their ability to use the full range of I 4.0 T, the supply of technology resources in the relevant settings for the efficient operation of plants, mainly skilled labour, is bound to be considerable. Technologically weak settings constitute an enabling factor for reshoring processes in these product fields, as evidenced by the relocation of Ford Motor Company's F-series pickup assembly plant from Mexico to Ohio, seeking control of the plant's design and production engineering as well as access to skilled personnel (Bals el al, 2016) and the relocation of F-650 and F-750 truck production, also by Ford, from Mexico to Avon Lake (Ohio), in this case to simplify and improve its engineering processes with a view to launching new, improved models more quickly (Pearce II, 2014).

5.1.2. *Low combinatorial complexity*

This describes a wide, heterogeneous range of production activities. From a technology viewpoint, it can be broken down into two types of product field according to the degree of technological complexity of the technical solutions used prior to the incorporation of ICT applications into their products and processes.

The first covers *low combinatorial complexity and high technological complexity* activities. This covers product fields that handle solutions with a strong scientific basis, e.g. industries such as chemistry, many pharmaceutical developments, machine tools and the electronics industry. Their low combinatorial complexity means that these are highly specialised activities from a cognitive point of view.

High technological complexity denotes business networks with a technology potential that has made them capable of developing in-house the technical solutions that they handle. The incorporation of new ICT developments that characterizes I 4.0 T into these product fields may therefore be expected to pose two problems of adaptation depending on the cognitive distance between the knowledge of the solutions handled and that of the ICT applications that need to be adapted.

Those who already have ICT knowledge will be better able to adapt their plants with their internal technology resources. For those who manage knowledge further removed from digital solutions, in-house technology is less useful, so the setting of plants is more relevant.

The fact that these are science-based activities means that plants can be expected to be located in settings with sufficient potential to make them operationally viable before the incorporation of the new I 4.0 T, so they are likely to be in a position to offer the resources of qualified manpower, technical assistance, training possibilities and technology services that make efficient adaptation feasible.

In short, the plants that handle solutions of high technological complexity can be expected to experience tensions in terms of reshoring. Those tensions will increase as the weakness of the technology setting in which they are located and the cognitive distance between the knowledge of the solutions they handle and those that make up the digital applications that need to be adapted grow.

A case in point is the relocation of General Electric's water heater production from China to Louisville, seeking greater proximity to its laboratories so as to apply new product solutions and facilitate the process of generating new designs (Moser, 2013). Another is the relocation from China to France by Kapsys, a manufacturer of digital mobility and communication devices for the elderly and visually impaired, of the production plant for its new Smart Vision cell phone model, to improve product quality and facilitate relations between the production team and the R&D department (Reshoring Eurofound, 2016; SMT.iconnect007, 2016).

The second covers *low combinatorial complexity and low technological complexity* activities. The lower technological requirements derived from low technological complexity mean not only that the fabric of business operating in these product fields has limited technology potential, but also that the sites of its plants abroad were chosen based on destinations that offer favourable operating costs. These can, logically, be expected to coincide with areas of low technology potential. The technological shortcomings of companies in terms of incorporating digitalisation into their plant operations can also be expected to reinforce the importance of the setting where plants are located: it needs to offer the necessary skilled labour resources, technical assistance, training possibilities and technology services. Given that they include activities located in low-potential settings, the incorporation of I 4.0 T can be expected to lead to scenarios in which there is intense pressure to reshore for technology reasons. This is the case of plants in industries such as plastics or textiles, which are in locations chosen for reasons of competitiveness, taken cost arguments into account. Such settings could well have limited technology potential.

The case of Roy Lowe & Sons is a good example of this scenario. Following the launch of its new lines of technical, sports, leisure and work socks, it moved production from its plant in China to Sutton-in-Ashfield and justified reshoring on grounds of product quality needs and proximity to its R&D laboratories (Eurofound, 2019a; Hills, 2017).

5.2. System manufacturers

This heading comprises products that need to meet certain measurable performance requirements, and to converge with the rest of the systems in the end product. To the extent that systems are part of a value chain, cooperation and logistics requirements play a relevant role in their operation. System manufacturers work in accordance with a logic in which specialising in the production of a certain component of the end product requires, for reasons of economic efficiency, a volume of production much higher than needed to meet the demand of a single customer.

From a cognitive point of view, the production of systems uses technical solutions of low combinatorial complexity with knowledge that can be of low or high technological complexity.

5.2.1. Low combinatorial complexity and high technological complexity

This heading includes production activities such as the development of systems that are part of aeronautical production, e.g. aircraft wings or automotive braking systems or engines. This is a group of companies with a high technology potential: the strongly specific nature of the designs that they handle must not only provide measurable objectives in terms of performance but must also converge with the rest of the systems in the end product. These agents need to have innovation capabilities, which they must develop in cooperation with the end-product manufacturer. They are companies with a high technology potential, with a great capacity to adapt their plants to the requirements imposed by new scenario being drawn the industry 4.0 using their own in-house technology resources. To the extent that they already handle assembly technologies involving advanced manufacturing technologies, the cognitive composition of those resources is sure to be close to I 4.0 T.

On the other hand, the need to meet the logistical requirements imposed by manufacturers, which are very stringent, for example, in the automotive industry, enables firms to accumulate relational skills through learning-by-doing processes, deposited in the plant that carries out those processes, which strengthen the plant's competitive position.

The resources offered by the settings in which these plants are located are also relevant for the purpose of adapting their resources to guarantee their operational functioning. The scientific basis of their technical solutions means that plants can be expected to be located in settings with sufficient potential to make them operational before the incorporation of the new I 4.0 T, so they can feasibly offer what is needed to adapt efficiently to the new operating conditions.

Added to this is the fact that each plant has a stock of accumulated relational potential that is lost if it is reshored, so such companies can be expected to be less likely to engage in reshoring. Their reluctance to reshore is likely to increase with the weakness of their setting in terms of technology. The reshoring of Ford's hybrid transmission plants from India or of its battery packs from Mexico is driven, according to the company, by the pursuit of improvement in innovation processes and by difficulties in finding qualified personnel (Moser, 2013).

5.2.2. Low combinatorial complexity and low technological complexity

The low technological complexity of the components used in their processes enables these companies to apply a localisation logic that looks for cost advantages in their operations. However, given that they engage in assembly operations, usually through automated processes, the host location selected must have not only cost advantages but a technology potential that enables them to meet the need to train personnel to handle processes that incorporate advanced manufacturing technologies. The specific nature of the technology used by system assemblers, designed to meet the specific needs of the end product of which the system forms part, determines whether the technical solutions used can be based in-house.

The technology gap between the technology potential of a company and the needs stemming from the incorporation of new I 4.0 T conditions the viability of technology adaptation processes with the company's resources and the extent of the role played by the settings of plants as enabling factor for reshoring. The role of its setting, which must meet the needs for skilled labour, training, technical assistance and the supply of technology services, is fundamental not only from the operational point of view of the plant but also as a mechanism that completes the technology potential of the company for the purposes of technology adaptation.

Furthermore, the logistical requirements derived from companies' positions in the value chain enables them to develop a learning process through which they accumulate relational competencies which are deposited in their plant, reinforcing their competitive positions.

When the fact that these are companies with low disinvestment costs is factored in, their plants can be expected to be highly sensitive to reshoring, closely linked to the inability of their settings to offer technological resources of the quality that they need. Superstar Components, a pedal set manufacturer, moved its production from Taiwan to its headquarters in Lincoln, UK to improve control of the production process and improve product quality (Reshoring Eurofound, 2016; Dalrymple, 2016).

5.3. Manufacturers of parts/components

This group comprises a very wide range of businesses: they handle process technologies, such as forging, machining, plastic injection, etc., in making the components that they manufacture. Their output forms part of different value chains and is aimed at system or end product manufacturers (customers). They are small companies which, logically, may be internationalised, seeking an optimal combination of proximity to the market and favourable cost conditions. The limited scope of their manufacturing tasks also limits the technological complexity of the technical solutions that they handle, which depend mainly on the degree of automation achieved in their processes. The characteristics of the products that they work with are based on closed designs in accordance with customer specifications, entailing very limited relational requirements. This is what Gereffi (2005) calls "market relations".

The incorporation of component manufacturers to industry 4.0 framework implies a need to adapt knowledge, that of ICT applications, from fields not handled by companies with limited internal technology potential. When internal technology potential is weak, the external setting of each plant becomes more important in carrying out a process of technology adaptation with knowledge subject to strong proximity constraints. This is a common assumption in these manufacturers if the novelty of the knowledge incorporated and their technological limitations are taken into account. The external setting needs to offer the human and training resources, plus the technological and technical assistance services needed to make it possible to articulate technical, organisational and management responses both to adapt products and processes to technology changes and to meet the new demands posed by plant operation. Having properly skilled personnel is essential for the

Type of company	Cognitive composition of technical solutions	Intensity of reshoring
End product Manufacturers	High combinatorial complexity with high technological complexity	Low, in general. The ability to use the whole range of new ICT applications increases the importance of context as an input of resources for the efficient operation of production plants. Interest in reshoring would grow with the technological weakness of the offshoring context and decreases in disinvestment costs.
	Low combinatorial complexity with high technological complexity	Limited. The importance of context in adaptation tasks is growing for those plants that work with technical solutions far from ICT knowledge. For them, the technological weakness of the offshoring context increases interest in reshoring.
	Low combinatorial complexity with low technological complexity	Intense pressure to reshore. Limited technology requirements favour localisation in search of favourable cost conditions in technologically weak contexts.
System manufacturers	High technological complexity with low technological complexity	Low sensitivity of plants to reshoring processes. The greater the relational demands with which the plant works are, the more likely it is to reshore. The technological weakness of the context can explain interest in reshoring such plants
	Low technological complexity with low technological complexity	Sensitivity to reshoring processes. Particularly dependent on the technological weakness of the context in which plants are located. The greater the relational demands with which the plant works are, the more likely it is to reshore.
Part/component Manufacturers	Low combinatorial complexity with low technological complexity	Particularly sensitive to reshoring processes plants with limited internal potential, located in technologically weak contexts. The general nature of their processes means that their markets are highly competitive, which determines the need for efficient adaptation of ICT applications.

Fig. 2. Typology of scenarios for reshoring for technology reasons in industry 4.0
Source: Own work.

efficient management of processes which involve universal tasks and are thus subject to strong competitive demands and are easily replaceable on the market.

Finally, it must be pointed out that technological weakness in the setting where a plant is located is the fundamental enabling factor for explaining reshoring decisions by these agents for technology-related reasons.

The company "Fine Scandinavia" (Konga Mekaniska Verkstad AB group) is a clear example of the importance of the setting in meeting the growing technology demands posed by technology dynamics among producers of this type. Despite having a high internal technology potential, which enabled it to incorporate I 4.0 T into the design of its components, in 2018 it moved some of the product lines that it was manufacturing at its plant in Vietnam to its Anderstop headquarters. This decision was based mainly on the availability of highly skilled labour in the Anderstop region (Reshoring Eurofound, 2018; Mellergårdh, 2018).

Fig. 2 summarises this typology of scenarios and sensitivities to reshoring.

6. Conclusions

The incorporation of I 4.0 T into the technical solutions handled by product fields in manufacturing industry raises technology adaptation needs within the framework of each company's production plants, with consequences also at territorial level. The results and costs of this adaptation process depend on: a) the resources that make up the technology potential of the company involved; and b) the technological resources that can be provided by the setting in which each plant is located.

We distinguish six technology profiles for manufacturing activities working within the framework of industry 4.0 as a whole, which we use as a conceptual basis to identify the characteristics of the technology-related scenarios in which we analyse the reshoring processes. We identify the likelihood of reshoring of plants located abroad according to the degree of similarity between its technology situation and that involved in the technology scenarios established.

Our main findings can be summarised as follows:

1. The incorporation of digitalisation into products and processes seems, in general, to exert varying degrees of pressure on the location of manufacturing industry plants concerning reshoring. It reinforces the increasing concentration of manufacturing activity in the most highly technologically developed areas, and defines the "digitalisation" of economic activity as the priority objective of industrial policy.
2. The proximity constraints that affect the resources that make up companies' internal technology potential in their countries of origin determine how fundamental the role of the technology available in the setting where a plant is located is in explaining the potential territorial effects of digitalisation and, consequently, the likelihood of reshoring. The new generations of I 4.0 T, which are increasingly complex and have a strong scientific base, pose problems of adaptation that call in varying degrees for resources such as technology services, technology consultancy, training and, above all, skilled personnel which, subject to proximity constraints, must be present in the setting where the plant is located. Plants in settings that do not offer the technology resources needed for efficient adaptation will be more likely to be reshored.
3. In line with the above argument, plants in settings with a low technology potential are more likely to be reshored. The plants affected most are those that handle solutions with low technological complexity, whatever the type of manufacturer, because they have a lower internal technology potential. Moreover, to the extent that they can take advantage of the low technology demands posed by their operations, such plants have the possibility of locating in settings that offer more favourable cost conditions, which in turn are likely to be technologically weaker.

The results of our analysis of the various technology profiles enable us to state that plants in product fields with high levels of technological complexity are in a better position to carry out technology adaptation processes. They have a greater internal technology potential, and consequently a greater internal ability to adapt their plants to new technology requirements. They are also usually located in settings with a technology potential great enough to support their activities. Such settings are, a priori, able to offer the resources needed to incorporate I 4.0 T efficiently into their products and processes. The lower likelihood of reshoring does not prevent them from being affected by these processes. The fundamental reference is given by the cognitive distance between the resources offered in the setting and the requirements posed by digitalisation. This difference can be observed in industries that handle knowledge which is scientifically based but from fields far removed from those that use the new technical solutions and located in settings that do not offer such applications; and in those that work in product fields of high combinatorial complexity that can use a wide range of new I 4.0 T (e.g. the automotive industry), in which the technology demands placed on the setting are very strong.

Finally, our study is affected by limitations arising from the highly general, aggregate approach taken in focusing on manufacturing industry as a whole. Accordingly, applying the method proposed to more specific production settings (at plant, product field or industry level) is a rich field for further studies into reshoring.

CRediT authorship contribution statement

Javier Bilbao-Ubillos conceived the ideas and the theoretical framework, and was in charge of Project administration; Vicente Camino-Beldarrain was in charge of the design of methodology and formal analysis; Vicente Camino-Beldarrain and Gurutze Intxarburu-Clemente led the writing; Eva Velasco-Balmaseda was responsible of the provision of study materials; Eva Velasco-Balmaseda and Javier Bilbao-Ubillos revised and finalized the text incorporating conclusions and policy implications.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

No data was used for the research described in the article.

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