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Catching the wave: Industry 4.0 in BRICS

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Catching the wave: Industry 4.0 in BRICS

Abstract

Purpose: This research aims to conduct, to the best of our knowledge, the first systematic review of the implementation of Industry 4.0 in BRICS. This review facilitates the identification of main factors that affect to the readiness to adopt Industry 4.0 in BRICS and the role of different agents, such as multinationals, the public sector or educative institutions.

Design/methodology/approach: Key publications published from 2010 to 2019 have been analysed. A total of 61 papers have been selected from the systematic review.

Findings: Three factors of convergence of BRICS to developed economies in terms of Industry 4.0 are identified: a) the public initiatives that can also result in the attraction of talent from developed countries to BRICS; b) the role of multinationals; and c) the implication of educational institutions.

Research limitations/implications: This review has some limitations. Firstly, some grey literature, such as reports from non-governmental organizations and front-line practitioners' reflections, were not included. Secondly, only research studies in English were reviewed.

Practical implications: The heterogeneity of BRICS amongst themselves affects the implementation of Industry 4.0 policies. Therefore, public policies should differ among countries to achieve the different readiness of companies within each country. Industry 4.0 cannot be understood as a manufacturing strategy against delocalisation, as emerging countries, such as BRICS, are also aware of the potential of automation.

Originality/value: Based on a systematic review, this article shows that the strategy created by Germany to increase industrial productivity has been also introduced in BRICS as a critical factor to improve their competitiveness.

1. Introduction

Industry 4.0 was first implemented in Germany to improve the competitiveness of their manufacturing sector and avoid delocalisation of factories (Pfeiffer, 2017). Nevertheless, in a globalised economy, main advances from a territory are rapidly expanded to other countries. However, this economic upgrading dynamic does not materialise for everyone, but it mainly happens in developing countries (Bernhardt & Pollak, 2016). As a result, the Industry 4.0 market experienced substantial global growth in developing economies, and, consequently, government industrial initiatives in the mentioned countries have been carried out in order to boost its presence in the industrial sector. In fact, although advanced economics located in Europe and the United States have been the enhancers in terms of application of smart factories, public initiatives towards the implementation of Industry 4.0 can be found in Japan, Brazil, China or Russia, among others (Min et al., 2019).

This state is even more relevant in the group of countries formed by Brazil, Russia, India, China and South Africa (coined "BRICS"), as these countries could become, by 2050, among the four most dominant economies (Kumar *et al*., 2017). To achieve this goal, the development of the manufacturing sector is crucial, and Industry 4.0 is an essential factor for the future of the industry. As a result, the implementation of Industry 4.0 involves an interesting area of research that has attracted the interest of researchers. Specifically, several authors analyse the role of public policies in BRICS to foster the implementation of Industry 4.0 (e.g., Zhang *et al.*, 2016; Fengque *et al.*, 2017). Along this line, other research focuses on the analysis of case studies about Industry 4.0 (Calitz *et al.,* 2107, among others). There is also a growing body of literature with rigorous analyses of recent experiences in different countries from BRICS (Cardoso *et al*., 2017; Dewa *et al.*, 2018). Nevertheless, to the best of our knowledge, there are no publications dealing with the situation of Industry 4.0 in BRICS on the whole. According to Dalenogare *et al*. (2018, p. 386), "as the concept of Industry 4.0 is relatively new, there is a high uncertainty and lack of knowledge about the real impact and contribution of the Industry 4.0 related technologies in the context of emerging countries in general". This is precisely the gap that this article aims to fill.

In particular, this research contributes to the study of Industry 4.0 in BRICS by 1) conducting, to the best of our knowledge, the first systematic review of the implementation of Industry 4.0 in BRICS; 2) developing the identification of main

factors that affect the readiness to adopt an Industry 4.0 framework; and 3) considering the role of different agents, such as multinationals, the public sector or educative institutions in this field.

To sum up, this article proposes an updated review of previous research on the implementation and development of Industry 4.0 in BRICS. The objective is to synthesize the available evidence on this field and to evaluate the sectors or specific areas within business where Industry 4.0 has been applied and the extent to which it has been applied in BRICS countries.

To address these purposes, the article is structured as follows. The first section describes the theoretical background. Section 3 presents the methodology and the search conducted. The results are included in Section 4. The paper closes with the main conclusions and discussion.

2. Theoretical background

2.1 Industry 4.0. Concept and the history of its development

The basic concept of "Industry 4.0" was first presented by the president of the Science and Engineering Academy, Henning Kagermann, at the Hannover Industrial Fair in 2011. In 2013, the report "German manufacturing in the future: Suggestions for implementing the strategy of Industry 4.0", confirmed the beginning of the actions planned by the German government. Therefore, the concept has its origin in Germany, which has one of the most competitive manufacturing industries in the world, where its government has traditionally supported the development of its industrial sector, with Industry 4.0 acting as a strategic initiative to contribute to its economy (Pfeiffer, 2017).

According to several scholars, there is not a commonly accepted definition of Industry 4.0 (Bauer *et al*., 2014; Hermann, *et al*., 2016; Piccarozzi *et al*., 2018). Along this line, as was noted by Hermann, *et al*. (2016), discussing the topic of Industry 4.0 from an academic perspective is quite difficult and requires time. Consequently, terminology should be a priority for further developments in a scientific field of research. For that reason, Erro-Garcés (2019) proposed the unification of terminology as an area of further research in the field of Industry 4.0.

However, several characteristics of Industry 4.0 are generally recognised: the horizontal integration of Industry 4.0 across the supply chain; the end-to-end digital integration of engineering across the entire value chain or the vertical integration and networked manufacturing systems. In general terms, the main characteristic has to do with the horizontal and vertical integration allowed by the Industry 4.0, and the complete interconnection across the entire life-cycle of products: from manufacturing to recycling (Kagermann *et al*., 2013; Chen, 2017).

Technology enables these changes. Consequently, Industry 4.0 represents the current trend of automation technologies in the manufacturing industry allowed by several technologies such as the cyber-physical systems, Internet of Things and cloud computing (Xu *et al*., 2018). In fact, this technological basis is composed by the combination of cyber-physical systems, the Internet of Things (IoT) and the Internet of Systems, which were implemented in order to create a technological network of intelligent production, where computers, devices and systems are connected and communicate amongst themselves. As a consequence, the classical production system

has changed into a new, self-organizing, cyber physical production system, leading to more efficient and productive smart factories. These changes are recognised as the Industry 4.0, the Smart Factory or the fourth industrial revolution (Lu, 2017).

2.2 Characteristics, benefits and challenges of Industry 4.0

Main benefits from Industry 4.0 come from the possibility of improving the production process. Nevertheless, also other economic benefits are identified, as well as social and ecological advantages (Kiel *et al.,* 2017).

Regarding the economic advantages, one of the main benefits of Industry 4.0 has to do with the capacity of smart factories to respond in a faster way to demand, influenced by the dynamics of the market. This flexibility results in a customized product, adding value to the outputs produced and leading to an efficient and successful business model and marketing strategy. Overall, Industry 4.0 enables the adjustment of production to the market needs, and the customization of products in a fast time deliver to market (Brettel *et al*., 2014; Kiel *et al.,* 2017; Mohamed, 2018). These benefits are the result of real-time production and the virtualisation of supply chains (Brettel *et al*., 2014) where all the stages of the production process can be digitized, generating autonomous factories and self-manageable supply chains. This allows for the integration and interaction of the different production stages (R&D, design, production and distribution), boosting the value chain for the new management and control system. In addition, this new process leads to a more sustainable production (Luthra & Mangla, 2018; Müller *et al.*, 2018).

The role of machines has changed from the third industrial revolution in the sense of how they interact with manufacturers. Manufacturers, instead of operating with machines, are able to communicate with computers – thereby computers are becoming independent entities that are able to collect data, analyse it, and advise upon it (Zheng *et al.*, 2018).

Indeed, the main benefits that can be derived from the implementation of the technologies and systems within Industry 4.0 are the increase in flexibility, mass customization, increases in speed, better quality of products and improved productivity in manufacturing (Brettel *et al*., 2014; Kiel *et al.,* 2017).

Finally, globalization of markets is playing a central role in the business scope, as businesses need to adapt in the fastest possible way to the requirements of an increasingly challenging demand, while trying to remain profitable and efficient.

Multinationals play a relevant role in this context (Telukdarie *et al.*, 2018). Apart from the benefits that the integration of the Industry 4.0 can produce, it is important to mention the challenges analysed by Prisecaru (2016), with implications for business entities and for society as a whole. These include implications for security and privacy, as well as its impact on capital and employment.

2.3 Industry 4.0's main research fields

As mentioned, Industry 4.0 has attracted the attention of academia, and scientific publications in the field have intensely increased. In this context, Lu (2017) or Ghobakhloo (2018) synthetized the main contributions of previous research through a systematic review. These contributions can be classified in the following topics: terminology, operations, technology and human resources.

Regarding terminology, several scholars highlight the need for systemic knowledge of smart industry. To quote an example, Bauer *et al*. (2015), Hermann *et al.* (2016) and Piccarozzi *et al.* (2018) affirmed that there is not agreement on the definition of Industry 4.0. Furthermore, the identification of standards is also required to facilitate the communication among factories and are strongly recommended in the literature (Li *et al*., 2018; Erro-Garcés, 2019).

Other articles are based on technological issues, covering topics that range from specific platforms to foster cooperation between companies, to program languages that support this relationship (e.g., Xu *et al.,* 2018). Technology related to real-time decisions is also considered.

Regarding the effects of smart industries on organisations and strategy, Lean methodology has been implemented to facilitate the introduction of Industry 4.0. Kolberg and Zühlke (2014) coined the term "Lean Automation" to describe the relationship between intelligent industry and the Lean system. Along with this line, Ghobakhloo and Fathi (2019) conducted an experiment to show how to develop a lean-digitized manufacturing system. This approach has also been probed in the developing countries (e.g., China: Zhang *et al.*, 2019a, 2019b, 2019c; Brazil: Tortorella & Fettermann, 2017).

The human resources effects of Industry 4.0 are the main topic in most of the articles in the field. Romero *et al*. (2016) defined the "employee 4.0" as a qualified worker that develops his or her work, helped by machines. Furthermore, papers by Lasi

et al. (2014) and Roblek *et al.* (2016) stated that Industry 4.0 issues are human resource issues. Finally, Veile *et al.* (2019) considered the need of integrating employees into the implementation process and establishing an open-minded and flexible corporate culture to support the implementation of Industry 4.0. In addition, job losses or employee requalification are identified as risks of Industry 4.0 implementation by Birkel *et al.* (2019), among others.

To summarize, automation of the production process is the main issue regarding operational issues. Precisely, our analysis is focused on the main fields within Industry 4.0 that have been explained in this section, through the following categorization: operational issues; human resource challenges; government industrial policies; readiness for the implementation of Industry 4.0 in BRICS countries; and the challenges that this adoption will trigger for these countries.

3. Methodology

This article analyses the publications of papers, articles and empirical studies focused on theories, practical experiences and key elements about Industry 4.0 developed in emerging countries. In order to synthesize the body of evidence of the specific topic treated, a systematic review of extant literature has been performed to examine these publications about the adoption of Industry 4.0 in BRICS. According to Torraco (2005) and Tranfield *et al.* (2003), a systematic review is an effective research strategy to analyse the experiences, problems and principal debates based on literature reviews, which justifies the method used in the research.

3.1 Strategy and inclusion criteria

The articles used to conduct the analysis have been retrieved from different databases, such as Sirius, Scopus, Dialnet, EconPapers, Web of Science, Social Science Citation Index and Google Scholar. Additionally, the process has included screening to avoid duplicates. For that purpose, the selected articles were collected and categorized in a database executed in Microsoft Excel. Moreover, reference management software and researcher network Mendeley has been used to store, manage, quote, reference and populate the bibliography[1].

The years of publication of the articles selected range from 2010 to 2019, with more than 85% of the total articles being from 2016, 2017, 2018 and 2019. Even more, just 2 or 4 articles were published in the first years. This evolution justifies the period selected for the analysis, as Industry 4.0 in BRICS appeared to be relevant appeared to be at the beginning of this decade. Finally, the searches were conducted in February 2019 and updated in April 2019 and November 2019.

Two main categories of terms have been used in the search of the selected articles. The first involves the concept of Industry 4.0 where the following terms have been searched: “Industry 4.0”; “smart factory”; and “intelligent industry”. The second category refers to the place where this technology is applied, that is, in emerging countries. Therefore, the terms “emerging countries”; “BRICS”; “developing countries”; “developing nations”; “emergent nations”; and “underdeveloped nations” have been used. In addition, the names of the specific BRICS countries have been also included.

[1] The database is available upon request to the authors.

The full search has consisted of linking the different terms of the two categories in order to find articles dealing with Industry 4.0 in emerging countries. For that purpose, the BRICS countries have become the central focus of this article. The criteria for the selection assumed that if any of these two categories of terms did not appear in the title or in the abstract of the articles, our topic of analysis would not be explained there, and therefore, the article could be excluded.

The first search from the Web of Science generated 313 results and showed growing interest in the publication of articles in the field in the years analysed.

From a total of 313 papers identified in the search of the electronic databases, 3 more papers were identified through other sources. Duplications, publications in other languages (10 articles published in Russian, 6 in Portuguese, 2 in German and 1 in Chinese), and articles from other fields (e.g., Biology, Occupational Health, Agronomy, etc.) were excluded. Therefore, a total of 64 full-texts were assessed for eligibility. Three papers were omitted because they were not focus in the field. All in all, a total number of 61 papers were included in the analysis.

Figure 1 shows the flow chart that identifies the different phases of the literature review.

Insert Figure 1 Here

The information collected from the selected articles includes the take-home message of each paper, authors, journal, year of publication, information about the samples, evidence and areas of knowledge. Concerning the classification of the selected publications, several functional areas were identified after reading the full-text articles from the selected publications and taking into consideration the theoretical framework developed in the research. The mentioned topics were: operational issues, human resources challenges, industrial policies implemented by the governments, the level of readiness of the country for the implementation of Industry 4.0 technologies and systems, and the challenges and problems faced in the adoption of Industry 4.0.

The database of the literature review was structured by the contents of the papers, comprising a total of 61 articles. Additionally, a differentiation of the articles by country in which Industry 4.0 has been implemented was observed. The BRICS country in which topics of Industry 4.0 have appeared most frequently is China, followed by India. Brazil and South Africa appear in the same number of publications, and, finally,

Russia is included in the least number of articles. Papers which contain a joint explanation more than one country amount to 8. Figure 2 shows this analysis.

Insert Figure 2 Here

4. Results

Previously to the analysis of the results by area, there are several results that affect to all the areas. Firstly, the low technological knowledge of the workforce of these countries raises concerns for a possible obstacle in the implementation of Industry 4.0 among these countries. In addition, there are different challenges acting as barriers for BRICS countries in their objective of becoming leaders in high-technology products. These characteristics impact to the implementation of the smart factory in BRICS.

In the analysis of the papers, the categorisation described in the theoretical background was carried out and the following mentioned fields of research in Industry 4.0 for BRICS countries were identified: operational issues (10 results); human resource challenges (16 results); government industrial policies (19 results); readiness for the implementation of Industry 4.0 in BRICS countries (7 results); and the challenges that this adoption will trigger for these countries (17 results). Other categories lead to 36 results.

These numbers reflect the relevance of operational topics and the role of the governments in the implementation of Industry 4.0 in BRICS. Although the importance of Industry 4.0 is a recurrent area of research in developed countries (Erro-Garcés, 2019), the dynamism of governments in this area is not so frequent.

A detailed analysis of the categorised fields is included in this Section.

Regarding the operational issues, industrial systems have completely changed with the implementation of Industry 4.0 because of the development of global physical networks, sensors, equipment and data exchange and control. Accordingly, the development of ICT in each country affects the adoption of Industry 4.0 (Bakkari & Khatory, 2016; Chen, 2017; Li *et al.,* 2018). Even more, it can be affirmed that the base of Industry 4.0 resides in the automation and in the data exchange in manufacturing technologies. In this context, several differences among countries can be posited. Thus, the technological development of China differs positively from the rest of BRICS, and, consequently, affects the introduction of Industry 4.0 (Li, 2018), whereas South Africa holds the last positions in technological advances (Dewa *et al.,* 2018). Nevertheless,

there are also important differences within each country. For example, Feng et al. (2018) evidence the differences in digitalization between China's urban and rural areas.

On the other hand, the emergence of global value chains has fostered the implementation of Industry 4.0 (Bernhardt & Pollak, 2015). In this sense, internationalisation allowed technology and knowledge transfer, and multinationals have a relevant role in the adoption of Industry 4.0 in emerging countries (e.g., Kitajima & Sakurai, 2019). Along with this line, logistics value chains will also be affected, as industrial companies are opening up to international markets. However, the challenge for the incorporation of automated processes is that it requires upskilling workers and the integration of local production techniques that will be analysed in the following subsection.

Conversely, alliances have been proved to be also relevant to improve performance in BRICS countries, such as in India (Roy & Satpathy, 2019).

In addition, the implementation of Industry 4.0 initiatives can even help industries to incorporate measures towards sustainability s as well as safety measures in the supply chains, as Luthra and Mangla (2018) evidenced in the Indian manufacturing sector.

In general terms, and according to our results, most papers analysed focused on the implementation of automation in the operational process. This is also the case in developed countries (Erro-Garcés, 2019).

The implementation of Industry 4.0 has a huge impact on human resources. There is a common belief stated by the majority of authors whose papers have analysed the labour force response with the application of Industry 4.0. They consider that the adaptation of human resources is one of the main challenges for the success of new forms of production derived from Industry 4.0. One of the main arguments is the lack of knowledge, talent and skills in core technologies (Cardoso *et al*., 2016; Sugimura, 2018). This is even more relevant in BRICS, where digital skills are below the global average (Huang *et al*., 2018).

A relevant debate is whether autonomous technologies would replace the human workforce or whether they would augment it. Blanchet *et al.* (2016), for example, expect a positive net effect between the disappearance of jobs and the replacement and creation of new ones whereas Calitz *et al.* (2107) study the impact of cobots (collaborative robots) on the African workforce.

Education is the key factor in this context. Iyer (2018) states that skill development is the differentiator of the successful implementation of Industry 4.0 in a global economy. The most cited solution is the preparation of the educational system for this scenario. Cardoso *et al*., (2016), Menegon *et al.* (2018), Sagar (2016) and Sugimura (2018) all argue that multidisciplinary capabilities should be enforced in education with the aim of equipping students and future workers with the sufficient knowledge in Industry 4.0 technologies. Organisational culture and the support of educational institutions (e.g. Universities) appears as a required factor in this context (Calitz *et al.*, 2017; Iyer, 2018; Abbas *et al.,* 2019; Zhang *et al.,* 2019).

All in all, authors agree on the necessity of investment in education in order to solve the problem of low levels of technological skills, knowledge and talent in BRICS countries. Even more, this investment contributes to attack qualified professionals, scientists, innovators and engineers from the rest of the world to these countries, increasing their competitiveness (Li, 2018).

Not only is technological development necessary to achieve industrial transformation, but institutional support also plays a key role in this change. Existing research identifies the presence of four different focuses within the global field of action. Figure 3 shows the different approaches of the United States, Europe, China, Japan and South Korea.

Insert Figure 3 Here

In general terms, European initiatives are focused on developing digitalisation opportunities while covering the needs of the labour market. On the other hand, the United States focuses on the development of innovative products and business models. China has concentrated its power in key technologies of advanced manufacturing, whereas Japan and South Korea support the establishment of strong local corporations in mechanical engineering and electronics (Chen, 2017). Within these four broad approaches, national and regional governments develop plans and initiatives for the launch of Industry 4.0, as is presented in Figure 4.

According to our results, there is an overall concern about the industrial policies implemented by governments, and more than 30% of the papers analysed lies within this field. The difference of this topic by country is significant. Most of the articles describe the policies implemented in China and India (Nam, 2011; Müller & Herzog,

2015; Koerber, 2016; Mohan, 2016; Wang, 2016; Wübbeke *et al.*, 2015; Wübbeke *et al.*, 2016; Zhang *et al.*, 2016; Fenghe *et a*l., 2017; Bishnoi, 2017; Zhong *et al.*, 2017; Rajput, 2018). For the case of Brazil and Russia, there are also papers explaining each situation, but to a lower extent (Boutenko *et al.*, 2013; Simachev *et al.*, 2014; Gausemeier *et al.*, 2016; Veselovsky *et al.*, 2019). Finally, no paper was found describing South Africa's policies.

Regarding the public interest in Industry 4.0, the 'Made in China' and 'Make in India' policies be identified for the development of the smart factory. These plans foster the implementation of Industry 4.0 in their corresponding countries by providing preferential access to capital to domestic companies (Li *et al.*, 2016; Fenghe *et al.*, 2017). Within Brazil's policies, the establishment of network society labs is taking place, so as to drive the Internet of Things innovation in that country, which affects positively to Industry 4.0. Lastly, the government of Russia issued a programme called the 'Development of the manufacturing industry and boosting its competitiveness in the horizon of 2020', with the goal of locally producing all materials required for robotics and electronics.

As a result, it can be concluded that Industry 4.0 that was mainly a public approach of Germany to increase the competitiveness of this country, has been extended to developing countries and their governments have rapidly incorporated public policies to foster the implementation of Industry 4.0. Although there are several differences between the government policies carried out by developed and developing countries (e.g. China versus Germany described by Wang, 2016, Zhang *et al.*, 2016; Kuo *et al.*, 2019 and Müller &Voigt, 2018), similar trends have also been identified (Wang, 2016; Mancilha & Gomes, 2018; Min *et al.*, 2019).

In fact, authors agree with the idea that the main objective of these industrial policies is the rapid development and modernisation of the industrial network for the economic wellbeing of the countries. Consequently, a convergence between developed and emerging countries in manufacturing policies can be expected.

On the other hand, the papers that analyse the level of readiness of industrial enterprises and of the economies as a whole agree on the importance of assessing this readiness as it affects the challenges faced in terms of internal and external factors in a substantial manner. In general terms, two types of factors can be identified: micro and macro-conditions.

Regarding the micro-conditions, the firm´s characteristics, such as the size, seems not to be particularly relevant in order to adopt the Industry 4.0 framework (Lin *et al*., 2018) whereas the strategy of the company, the intra-organisational communication, technologies implemented, employees, products/services and innovation are dimensions that influence the level of readiness of a company (Purdy *et al*., 2017; Swarnima, 2017; Tortella *et al.,* 2017; Dewa *et al*., 2018; Horvat *et al*., 2018). Equally, the relationships between companies located in developed countries and firms from the developing countries foster the implementation of Industry 4.0. To quote an example, the overcome of the challenges of Industry 4.0 can be facilitated by the global presence of multinationals that expand their methods from develop to emerging countries (e.g., Mana *et al*., 2018; Telukdarie *et al*., 2018). Along this line, the experience of Fujitsu in the use of digital data across countries is an illustration of this reality (Kitajima & Sakurai, 2019). Finally, cooperation among companies seems to promote the adoption of Industry 4.0 (Frolov *et al*., 2019). In this sense, the ecosystem is conceived as a strategic asset to facilitate this collaboration (Rocha *et al.,* 2018).

The previous literature also identifies impediments to the implementation of Industry 4.0 at a micro-level. In this line, a phenomenon identified by Dewa *et al.* (2018) and Aulbur *et al.* (2016) is the lack of awareness concerning Industry 4.0, which amounts to a significant obstacle for its adoption. In addition, Khachaturyan *et al.* (2018), Swarnima (2017), Purdy *et al.* (2017), Horavat *et al.* (2018) and Dewa *et al.* (2018) propose different models based on different criteria to evaluate the level of readiness of industrial companies situated in any of the BRICS countries.

Concerning the macro-level, Khachaturyan *et al.* (2018) present a model for Russian high-tech companies based on external factors that have an impact on technological development and that influence the level of readiness of this sector throughout a STEP analysis (political, economic, social, and technological analysis). The government industrial policies described in the previous subsection affect to this macro-level. Both the different levels of informatisation in the different countries (Li *et al*., 2018) and the existence of institutions that collaborate with companies to acquire the required knowledge (Abbas *et al.,* 2019) are also included in this macro-level.

In summary, there are different models to assess the level of readiness of a company, as can be seen in the literature outlined above, but there exists a common trend for the selection of these dimensions, which necessitates a full perspective of the

adequacy of companies to implement Industry 4.0 technologies in BRICS countries, by not only focusing on the micro-environment, but also on the macro-environment.

Finally, main challenges and problems of adoption of Industry 4.0 have been identified. Apart from the challenge concerning the lack of core skills and the poor digital infrastructure (Feng *et al.,* 2018), there are also other barriers for the implementation of Industry 4.0 in emerging countries.

Firstly, traditional cultures and values affect to the managerial approaches (Vasin *et al.*, 2018). Consequently, there is a need to substitute the traditional managerial approaches, principles and values (i.e. a profit or efficiency focus) towards priority goals and economic system success (i.e. a client, innovation and cooperation focus). Secondly, financial availability and uncertainty issues should be addressed, as Horvat (2018) recommends. Finally, standardisation appears as a fundamental aspect to overcoming the challenges of Industry 4.0 implementation is the standardization of industrialization resulting in a network connection and information integration between different companies (Li *et al.,* 2007; Feng *et al.,* 2018; Gausemeier *et al.,* 2016; Vasin *et al.,* 2018).

All in all, the main challenges for the adoption of Industry 4.0 in BRICS countries are the need to break with the traditional management approach, the poor technological infrastructure, the difficulty to scale for companies stuck in early stages of development and the need to identify funding for investment. Most of the authors claim the standardization of industrialization between companies to be a crucial solution to overcoming part of these challenges.

5. Conclusion

When Jim O'Neill coined the concept of "BRIC", his predictions showed that BRICs' combined economies would be larger, in terms of GDP, than those of the G6 (US, Japan, Germany, France, Italy and the UK) by 2050. Currently, the term "BRICS" is used to describe the fastest growing emerging markets, with the incorporation of South Africa to the list in 2011 (Bell, 2011). In more than a decade and a half, the combination of the BRICS economies has become a global power, being key producers of goods and services, investment destinations and the principal engine of new demand growth (Aulbur, 2016). As shown, this growth is supported in the development of the industrial sector. To aid this development, the expansion of smart industries should be

considered. As a consequence, the relevance of these countries in the global economic growth and the importance of Industry 4.0 for these countries justify the need for this research, which is focused on the role of smart industries in BRICS economies.

Although the German public sector was the first to promote Industry 4.0, several public policies have also been found in BRICS countries. Governments from China and South Korea implemented applications of key technologies and enacted massive construction of smart factories to promote their manufacturing sectors. Furthermore, Industry 4.0 national government initiatives have been identified all around the world. As a consequence, it can be stated that Industry 4.0 public policies have been implemented in both developed and emerging economies. This situation reinforces the idea of the existence of a global operational management framework and global interactions, as noted by Szász *et al*. (2018).

The current fourth industrial revolution is bringing about changes based on automatisms, data sharing and manufacturing technologies. This new system allows for mass customization of products and is characterized by its flexible mass production technologies. The incremental increase in productivity that its implementation allows is caused by the affordability of automation, which means that not only did companies located in developed countries need to change traditional manufacturing approaches, but also companies in emerging countries, such as Brazil, Russia, China, India and South Africa (in fact, BRICS countries). In this sense, as has been shown in the analysis, BRICS are aware of the relevance of Industry 4.0 (Ismail *et al.*, 2019).

As a result, BRICS economies are engaging in several measures to promote the implementation of Industry 4.0. Firstly, public initiatives in the field of Industry 4.0 have been developed in these countries (Bishnoi, 2017; Zhong *et al.*, 2017; Gausemeier *et al*., 2016; Veselovsky *et al.,* 2019). These policies reflect the interest of these countries in Industry 4.0.

Secondly, micro and macro-conditions to support the readiness of a company for the implementation of intelligent manufacturing have been identified. The strategy of the company, intra-organisational communication, technologies implemented, employees, products/services and innovation are factors to be quoted in the first dimension (Purdy *et al.*, 2017; Swarnima, 2017; Tortella *et al.*, 2017; Dewa *et al.*, 2018; Horvat *et al.*, 2018), whereas the collaboration of institutions and the technological level of the country can be recognised as macro-conditions (Li *et al*., 2018; Abbas *et al*., 2019).

Thirdly, the presence of multinationals and the cooperation between firms can also be highlighted as enablers of Industry 4.0 in BRICS (Mana *et al.*, 2018; Telukdarie *et al.*, 2018; Frolov *et al*., 2019).

In fact, the convergence of BRICS and developed countries in the field of Industry 4.0 depends of several factors, such as the implementation of public policies, the role of multinationals, the cooperation and the involvement of education centers that support workers in the process of acquiring the digital skills required.

However, there are specific challenges for the adoption of Industry 4.0 in BRICS countries. The need to break with the traditional management approaches, the poor technological infrastructures, the difficulty to develop specific businesses once a company has been established and the need for financing are problems that these countries should face to implement successfully an Industry 4.0 framework (Gausemeier *et al.*, 2016; Feng *et al*, 2018; Vasin *et al.*, 2018).

Finally, the number of publications in the field and the increment of articles in the last years confirm the interest of BRICS in Industry 4.0.

From an applied perspective, the heterogeneity of BRICS amongst themselves in terms of R&D expenditure, government policies and foreign direct investment should be considered (Bell, 2011; Liu, 2016). Therefore, the overall readiness of companies within each country is situated at a different stage, which implies different challenges and problems to be solved for each country in particular (Li *et al*., 2018). The analysis also has shown the predominant position of China above the rest of the BRICS countries in terms of its technological evolution (Li *et al*., 2018). As a result, public policies should differ among countries in order to achieve the different readiness of companies within each country.

On the other hand, Industry 4.0 cannot be understood as a manufacturing strategy against delocalisation, as emerging countries, such as BRICS, are also aware of the potential of automation for the industrial sector. Even more, globalisation allowed these countries to "join the squad" of the enablers of automation, and they are not going to miss the opportunity.

Finally, several limitations can be highlighted. Firstly, given the novelty of this field, the research about Industry 4.0 is consistently increasing. For that reason, future reviews are required in order to actualize the state of the art in this area. Concretely, the evaluation of the public initiatives in Industry 4.0 implemented in these countries can be an interesting are for further research. Best practices identification and the comparison

among these public policies may generate future outcomes in this field. On the other hand, case-studies that present the behaviour of multinationals in emerging countries are also interesting in a future research agenda. Secondly, most surveys do not include questions related to the digitalisation of firms in recent years. Although this is changing, it is difficult to find statistical data to analyse the evolution of automation, making this a fruitful area for further research.

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Figure 1. Search strategy and process. PRISMA Flow Diagram

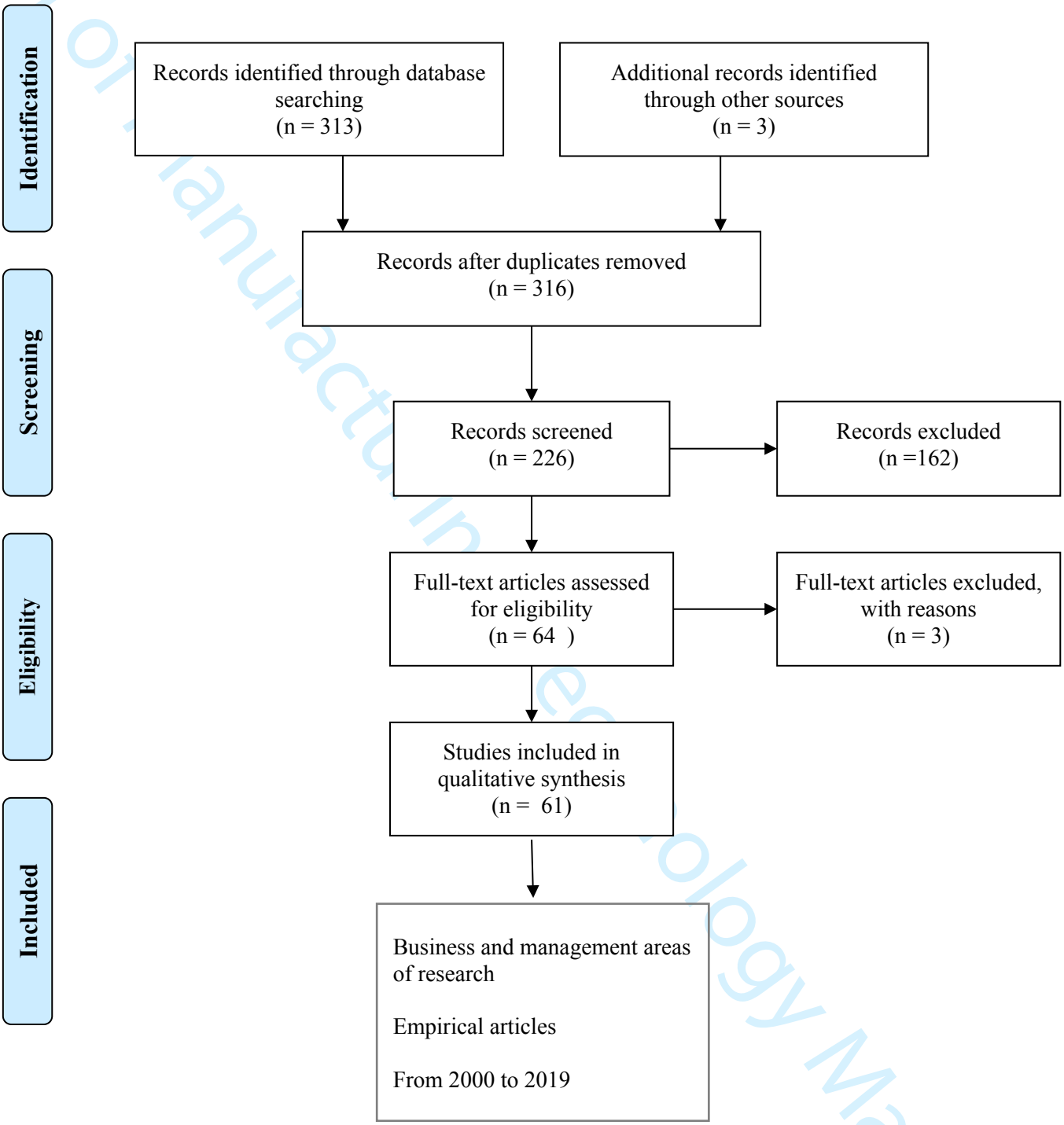
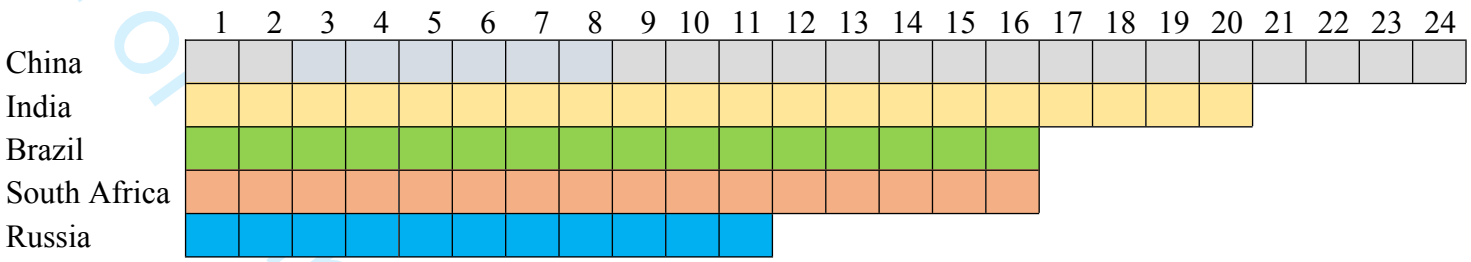
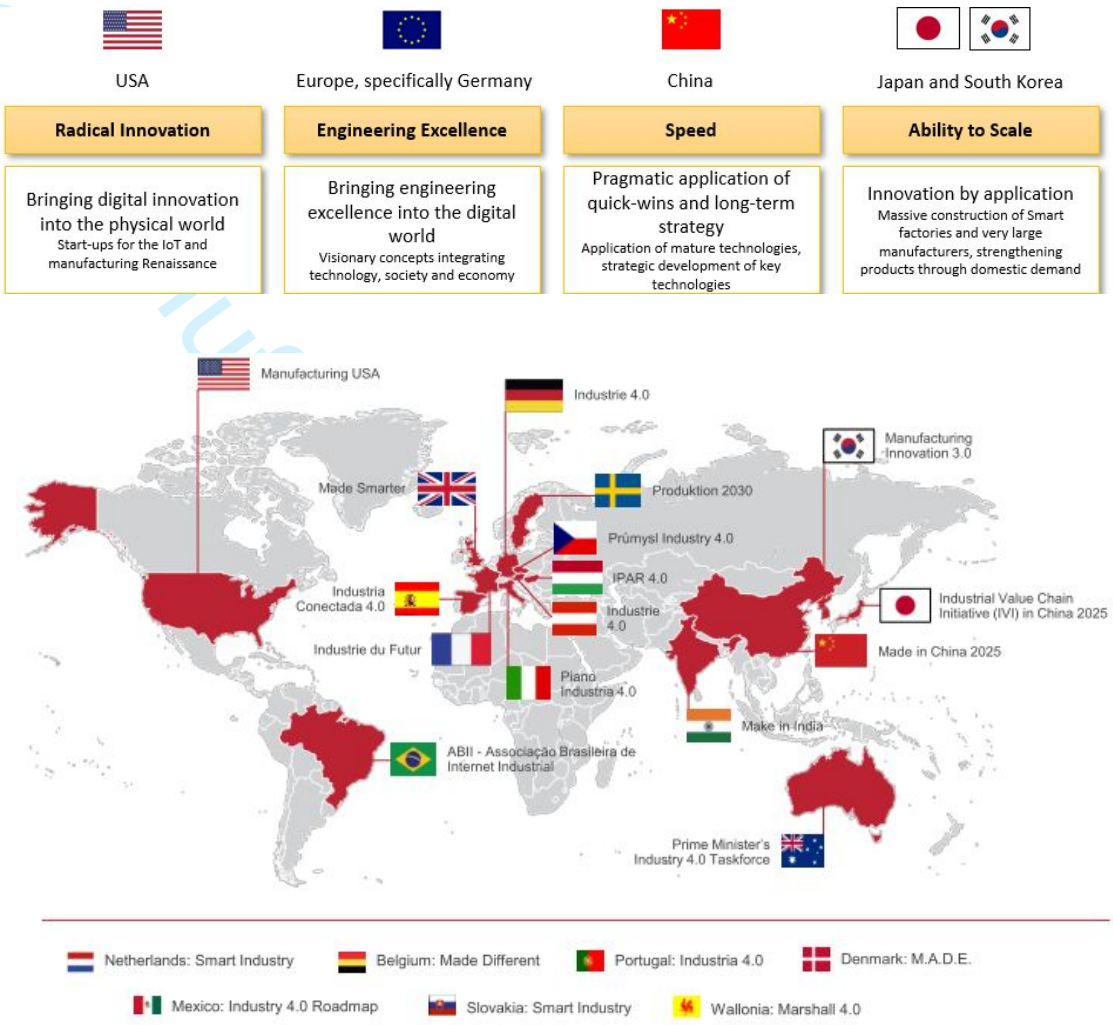


Figure 2. Number of articles of the analysis based on each BRICS country.



Source: Author's own.

Figure 3. Four approaches regarding Industry 4.0 in the world, and national government initiatives for Industry 4.0



Source: Gausemeier *et al.* (2016)