Contributions of Innovation Ecosystems in the Adoption of the Industry 4.0 Model in SMEs, a Bibliometric Study

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Abstract: *This work explores the creation of workspaces dedicated to enriching and facilitating the development of the industry 4.0 model in SMEs. The idea is to analyze the impact of innovation environments and its institutions in technological management and linkage to guide and boost in the Industry 4.0 productive framework with a relatively high density of SMEs. There are numerous local initiatives to disseminate and promote the adoption of the digitization model of productive companies known as Industry 4.0, following the model promoted by Germany and adopted by the EU, also known as Smart Manufacturing, according to the USA model. Finally, this paper analyses literature about SMEs, industry 4.0 paradigm, and Innovation Ecosystem, in a bibliometric study through the SCOPUS scientific database. The results show that innovation ecosystems, through the different edges that they deliver ease the adoption of the smart manufacturing strategy to the SMEs within their boundaries.*

Keywords: Industry 4.0, Innovation ecosystem, open innovation, smart manufacturing and startups.

1. Introduction

This work approaches the paradigm industry 4.0 and the way the link with innovation ecosystems affects the adoption of the novel productive model in SME. To begin the paper, it is going to be used the term industry 4.0 although the new industrial strategy is known as Smart Manufacturing, Fourth Industrial Revolution, among other terms depending on the bibliographic reference. The scope of the concept of industry 4.0 is broad and diffuse and could be treated from different views. Some more technocratic approaches are strong linked to industrial hardware and software, other authors more focus on social issues are concerned in the role of people and the future of work, from a technology management side could be interesting to study new business and operating models, open innovation, and the evolution of Global Value Chains, among many other issues.

Muhuri et al., 2019, consider that industry 4.0 is not just about industry. It is about overall transformation using digital integration and intelligent engineering. It is quoted as the next level of manufacturing where machines will redefine themselves in how they communicate and perform their functions.

An article from Deborah J. Jackson, 2015, PhD from Stanford who works at the Division of Engineering Education & Centres (EEC), National Science Foundation (NSF) gives an interesting definition of the concept of innovation ecosystem. She states that a biologic ecosystem is a complex system of relationships among living resources, environment, and residents in an area, whose objective is to a state of equilibrium. While an innovation ecosystem models the economy more than the energy dynamics of complex relationships among actors or organizations whose functional objective is to facilitate technological development and innovation. In this framework the actors would include material resources (founds, equipment, infrastructure, etc.) and the human capital (industrial researchers, industry representatives, academics, etc.) that integrate the institutions participating in the ecosystem (Universities, firms, state, NGOs, etc.).

Another reference to start with the innovation ecosystem issue is brought by Ben Ake Lundvall, 1992, who coined the concept of Innovation System. Lundvall points that innovation is produced by the interaction of three central actors, the government, academic and research institutions, and firms. It is by linking some main actors that the emergence of innovations, whether incremental or radical, is facilitated. In other words, learning by interaction and collective entrepreneurship are fundamental for the innovation process.

A paper from Walas Mateo & Redchuk, 2021, highlights the opportunities for development of new technological startups and adoption of the Industry 4.0 model in SMEs that emerge from innovation ecosystems in Argentina. That text states a conceptual framework that needs to be validated with other experiences in other latitudes with different boundary conditions.

The present work pretends to go deeper and focus on the benefits of innovation ecosystems in the approach of the Industry 4.0 strategy in SMEs around the globe. This article begins with the development of the conceptual framework of innovation ecosystems, then stablish the hypothesis to advance in a bibliometric analysis around the concepts of Innovation Ecosystem and SMEs associated with the industry 4.0 model. Methodologically, a technological mapping was carried out through an exercise on Scopus indexed databases, whose results were analyzed through bibliometric indicators. These indicators, refers about the main authors, evolution of the relevance of the concept. The analysis was completed through the use of the VOSviewer® 1.6.16 software tool, to analyze results. Then selected articled are scanned to find relevant concepts and reach the conclusions and lines of research raised in this work.

2. Innovation ecosystems and industry 4.0

To start the development of what the innovation ecosystem and industry 4.0 mean, it will be cited the German case developed by Schroeder, 2018. In this publication he mentions the existence of an Innovation ecosystem. Although he does not exactly call it that way, he mentions that various initiatives coexist from the political and economic sectors, as well as from interest groups and the scientific community. On the one hand, they act in part separately and compete with each other; but, on the other hand, they are closely linked in some sectors. Many initiatives are directly the responsibility of the political sphere and of the State, or they are promoted or even developed independently by companies with sufficient resources to do so. However, the relationship between the state and interest groups is also of some importance in industry, a relationship that could already be put under strain in the previous corporate landscape of German industry. This affects, above all, the global coordination of innovation, the formulation of standards and the creation of the necessary public infrastructures, something that is especially true when it comes to creating the most appropriate conditions and framework for the development of infrastructures (for example, increased broadband, industrial standards) and financial incentives (for example, taxation, investments) favorable for the implementation of the industry 4.0 strategy.

In the same work that it is referred in the previous paragraph, the importance of the triangle: politics, business and science, and the cooperation that must occur between the parties to mobilize resources and the necessary legitimacy for this is highlighted. Once this instance was achieved, the author describes how business associations and unions were incorporated.

It also highlights that the specific promotion of innovation is based on the sponsorship of knowledge-intensive SMEs and the need to improve the framework conditions for innovation, through the promotion of innovation groups in German universities, as well as through competence centers and knowledge platforms. Given that a high potential for innovation emanates from both existing and emerging SMEs (startups), their framework conditions should be promoted (among others, through networks with already established companies, provision of venture capital, and development of incubators, and incubators of companies).

On the other hand, in a study for the European Parliament (Smit et al. 2016) shows that Industry 4.0 will only be successful if certain requirements are met: standardization of systems, platforms and protocols; changes in the organization of work to adapt to new business models; digital security and protection of knowledge; availability of properly trained workers; Investigation and development. In addition, it mentions the challenges for SMEs in Industry 4.0 regarding value chains, costs, risks, reduction of flexibility, and reduction of strategic independence. He mentions that Government can play a role in creating an ecosystem that helps SMEs in the transition to the new model, although he indicates that little research has been generated in this area.

Another important reference, is given by the article of Da Silva et al., 2019, indicating that in Germany, the project that promoted the concept of Industry 4.0 brought together Universities, research centers, companies and national government, focusing on global competitiveness. It also indicates that the government has a fundamental role, through policies, techniques and infrastructure regulations, such as the expansion of digital networks, service improvements, economic benefits, incentives for education and research, among others. He finally highlights that the absence of these actions is a barrier to the adoption of Industry 4.0 concept.

After the references to the works of Schroeder, 2016, Smit et al. 2016, and Da Silva et al. 2019, it would seem that the ecosystem or platform is a central element for the dissemination of the Industry 4.0 model in industrial companies. Therefore, we will delve into the development of the innovation ecosystem concept, an element that it is believed to be central to the dissemination of the industry 4.0 strategy, in particular for SMEs, either to generate mechanisms that facilitate the implementation of the model in industrial companies, and in this way to boost the development of the demand for solutions and services, as well as for the generation of the technological offer and the creation of technological startups or technology-based companies that provide technological tools to nurture industrial companies. This last edge of innovation ecosystems is widely developed in the work of Walas Mateo & Acosta, 2020. On the other hand, the Ecosystem around the Industry 4.0 model is also necessary for the development of industrial standards and protocols, and above all to facilitate networking in global value chains.

3. Study hypothesis and bibliometric study

At this point in the work, having analyzed some evidence from the work considered as a starting point, it is possible to stablish the hypothesis in which this article is going to be focused. The central question to analyze is whether innovation ecosystems impact in the SMEs approach to an industry 4.0 strategy.

On the other hand, the research will inquire about concepts such as social capital, open innovation, collective efficiency, startups, among others, and their relationship with the industry 4.0 model and SMEs.

It will be developed a bibliometric application on the topic of Innovation Ecosystems, and Industry 4.0 to address the hypotheses raised before. Bibliometry and text mining is based on the search for statistically regular behaviors over time in the different elements related to the production and consumption of relevant scientific information. Thus, global explanations for the observed phenomena are achieved through the formulation of bibliometric laws: author productivity, bibliometric dispersion, exponential growth, scientific bibliographic obsolescence. Merediz-Solà & Bariviera, 2019, highlights the bibliometric discipline, which is being adopted aided by the easy access to scientific papers compiled and indexed in huge databases, making possible to measure different facts regarding research issues, like number of authors, keywords, topic, citations, institutional collaboration, etc. The rationale for indexing articles is the following: authors cite other papers due to its connection with the core idea of his/her paper.

Based on this premise, the objective of this work is the exploratory study through a bibliometric analysis on the concept of Industry 4.0 and Innovation Ecosystem. As a basis for the analysis, the article entitled "Industry 4.0: a bibliometric analysis and detailed overview" by Muhuri et al. 2019. This work provided an interesting sample of the state of the art of technology around the concept under analysis, based on the bibliometric study. The authors summarized the evolution and growth in relevance of the Industry 4.0 concept over the past few years, and provide concise background information and various areas of application.

Next, the experience of searching and processing information is developed to obtain the indicators around the Industry 4.0 concept that will serve to exercise the bibliometric analysis methodology.
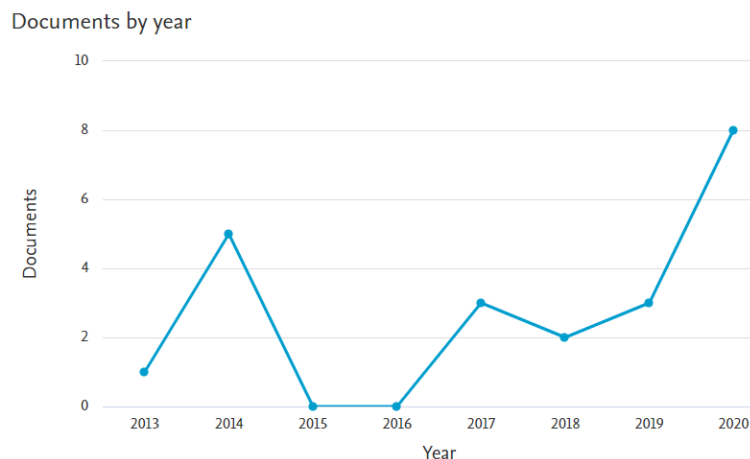
4. Methodology used at work

The analysis task began with the definition of the search criteria. In this case it is about the keywords, innovation ecosystems, industry 4.0, and the alternatives industrie 4.0, smart manufacturing, and production 4.0.

Once the keywords were established, the Scopus database was searched.

On the other hand, to select the keywords within the search, the terms mentioned above were taken into account. The keywords included in the title, abstract and / or full text were combined using the Boolean operators "AND" and "OR"
The search query used was the following:

ALL ("innovation Ecosystems" AND "Industry 4.0" OR "Industrie 4.0" OR "Smart Manufacturing" OR "Production 4.0")

Once the results were obtained, an analysis of main authors, evolution of the number of publications on the subject, and main countries of origin of the publications was carried out. Then the database was exported in CSV format, to analyse the results in detail. The export was carried out in two formats, the first with the information related to the complete bibliographic data, and then another file that contains only the keywords and the abstract of each paper.

Subsequently, the analysis was completed by screening the articles found in the search. Then the most relevant ones regarding the issue that is being analysed are listed and commented to extract the most significant concepts.

5. Results of bibliometric study

The search in the SCOPUS scientific database was performed on 15th June 2021, and yielded 22 results. The first parameter to be analysed is the evolution of the number of documents per year, which, as shown in figure 1, has been growing since 2013 when the first article appeared around innovation ecosystems and industry 4.0.

According what is shown in figure 1, the topic of this research is gaining strength and relevance, considering the evolution of the first article from 2013 to eight published last year.

Then it can be analysed the origin of the papers according to the country where they are written, which is shown in figure 2 below. It can be seen that the most prolific in the subject under study is USA with five works followed by Brazil and UK with three works each.
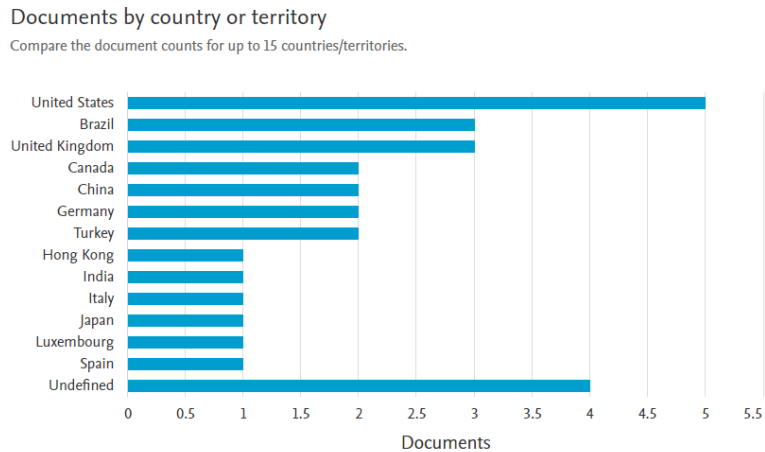

Figure 1: Evolution of the number of documents per year. Source SCOPUS

Figure 2: Origin of the papers according to the country. Source SCOPUS

Then the third item that was observed from the search at Scopus was the most prolific authors in the studied subject. To visualize the authors with more papers in the subject of interest for this paper is by using the tool VOSviewer. Then it was possible to see the concentration of authors in a more graphical way. Below in figure 3, it is shown the concentration of authors, based on the number of publications.
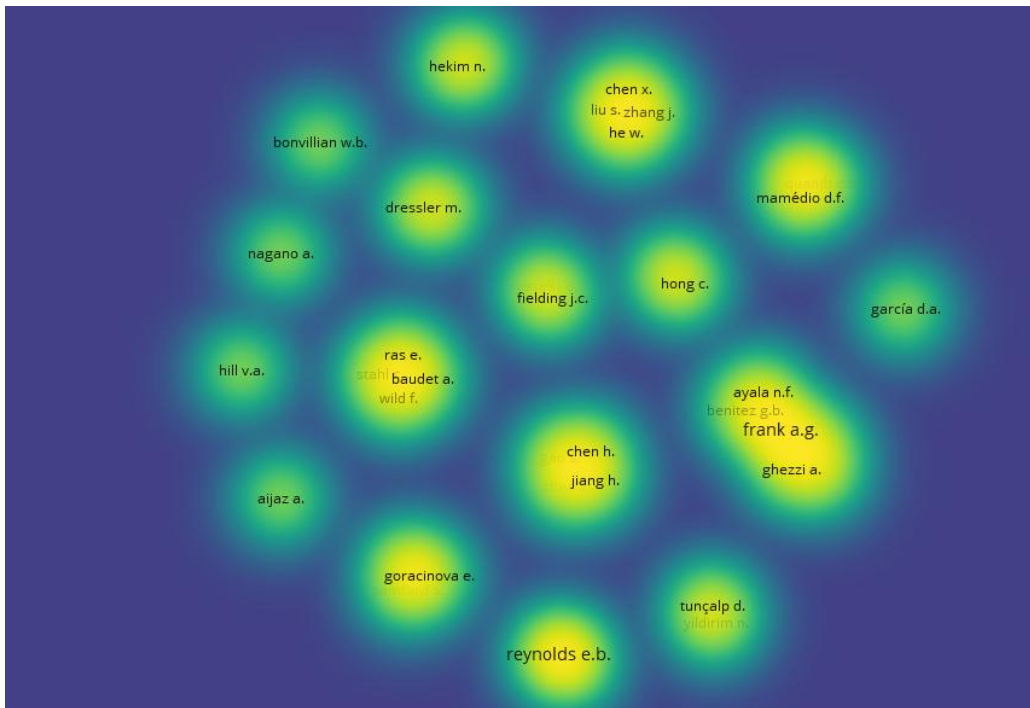

Figure 2: Concentration of relevant authors on Innovation Ecosystems, SMEs and Industry 4.0 at SCOPUS, generated with VOSviewer tool.

6. Scanning of Papers

The next step to complete the bibliometric analysis is to make a more detailed analysis with the papers containing key words of the field of interest for this work. In this way it is possible to validate the hypothesis raised earlier, regarding whether innovation ecosystems impacts in the SMEs approach to an Industry 4.0 strategy. All the 22 papers found on the search at Scopus data base were scanned to find evidence of the link among innovation ecosystems, industry 4.0, and SMEs.

When focusing in what the authors say about the relevance of innovation ecosystems to ease the adoption of Industry 4.0 paradigm in SMEs, eight works appear to be relevant for this paper. Below in Table 1 are listed the nine articles that have concepts linked to what is aimed with the hypothesis of this research.

The first work that has interesting content for this research is the one from Benitez et al. (2020) shows that the importance of innovation ecosystems for SMEs from the last eleven years has shifted from facilitating the access to innovation funds to Industry 4.0 solution cocreation and, then, to smart business platform collective creation. Besides, the paper also show how innovation ecosystems can help firm managers and policy makers to learn about technology development strategies in industry 4.0 ecosystems, and how to organize the evolution of such ecosystems respectively.

The work of Kahle et al. (2020) generated a conceptual framework to visualize the required characteristics of an innovation ecosystem to get Smart Products from SMEs, and discloses the relationships among these characteristics.

Liu et al. (2020) referrers the constraints of innovation are also prominent, especially for SMEs. In the context of global open innovation, the authors highlights implications that are proposed to promote the deep integration of enterprises into the global innovation chain to improve innovation capabilities to generate the upgrading of manufacturing SMEs into the new paradigm.

The findings that bring Dressler and Paunovic (2020) studying the wine industry 4.0, considers the importance of innovation ecosystems for small firms to adopt business models based on innovation (BMI) and cope with the requirements of the demanding wine market.

The study from Rocha et al. (2019) focus on the nature of startups collaborations in the development of digitalisation in Brazil and put on the table the difficulties and challenge that Industry 4.0 means. Aligned with this issue highlights the importance of partnerships within firms, academic sector, government development agencies, incubators. The authors observe the intense use of open innovation practices by startups.

Table 1: Papers with significant content about innovation ecosystems and the adoption of the Industry 4.0 model in SMEs

Authors	Title	Year	Source title
Benitez G.B., Ayala N.F., Frank A.G.	Industry 4.0 innovation ecosystems: An evolutionary perspective on value cocreation	2020	International Journal of Production Economics
Kahle J.H., Marcon É., Ghezzi A., Frank A.G.	Smart Products value creation in SMEs innovation ecosystems	2020	Technological Forecasting and Social Change
Liu S., He W., Chen X., Zhang J.	Innovation Ecosystem and Innovation Cooperation Networks: The Embeddedness of Global Innovation Chain of Guangdong's Manufacturing Sectors towards Industry 4.0	2020	Proceedings of 2020 IEEE International Conference on Artificial Intelligence and Computer Applications, ICAICA 2020
Dressler M., Paunovic I.	Converging and diverging business model innovation in regional intersectoral cooperation–exploring wine industry 4.0	2020	European Journal of Innovation Management
Rocha C.F., Mamédio D.F., Quandt C.O.	Startups and the innovation ecosystem in Industry 4.0	2019	Technology Analysis and Strategic Management
Yildirim N., Tunçalp D.	A policy design framework for digital transformation: University-based Innovation and Entrepreneurship Ecosystems Revisited	2019	Managing Technology for Inclusive and Sustainable Growth - 28th International Conference for the International Association of Management of Technology, IAMOT 2019
Reynolds E.B., Uygun Y.	Strengthening advanced manufacturing innovation ecosystems: The case of Massachusetts	2018	Technological Forecasting and Social Change
Samford S., Warrian P., Goracinova E.	Public and private goods in the development of additive manufacturing capacity	2017	Business and Politics

Source: SCOPUS

Another interesting work is brought by Yildirim and Tunçalp (2019). These authors remark the role of Science and Technology Universities in innovation ecosystems to drive technological innovation and entrepreneurship needed to adapt industry 4.0 technologies and digital transformation. Yildirim and Tunçalp (2019) left a proposal for a technology policy design framework that may help to develop innovation and entrepreneurship ecosystems centred in Universities for a digital transformation roadmap towards to promote innovation in strategic industrial sectors in Turkey as a case study for developing countries.

The work by Reynolds and Uygun (2018) is focus Massachusetts manufacturing innovation ecosystem with a particular focus on SMEs. The authors analyse how knowledge and sources of innovation is driven between key actors within the industrial innovation ecosystem. They consider the Massachusetts industrial innovation ecosystem rich in terms of assets but quite poor considering the link between those assets. Besides, rather than being focused on innovation driven by the demand and technological upgrading for SMEs, non-market manufacturing intermediaries state supported are primarily focused on supply-side, point solutions that work with individual firms rather than at a systems level. An interesting observation from this article is that the authors link the concept of cluster with innovation ecosystems.

Then Samford et al. (2017) focused on additive manufacturing to make visible the difficulties that SMEs face adopting new technologies and a decentralized policy effort to systematically increase the use of advanced manufacturing technologies. Then explain the case of funding used by community colleges to create applied research centres in Canada, The authors conclude that innovation ecosystems could provide information and working capital to SMEs, to ease the challenges to the adoption of additive manufacturing technologies.

7. Conclusion

At this point of the work it is possible to understand the different edges that innovation ecosystems provide to facilitate the adoption of the strategy of industry 4.0. It is interesting to note that there is general consensus among the authors on the complexity implied by the new production model, and the benefits that innovation ecosystems provide to tackle the difficulties for industrial firms in general and especially for SMEs.

Cocreation and open innovation, the role of Universities and Government, in particular the latter to ease the access to funding, are described in the different works revised. And although some key words that are named in the hypothesis,

early in this paper, such as social capital or collective efficiency don´t appear directly, it is possible to infer that innovation ecosystems provide this concepts easing the process into industry 4.0 strategy for SMEs.

Another point that emerged from the bibliometric study to solve the hypothesis of this paper is around entrepreneurship and the need to foster the development of startups to generate an offer of solutions to help the industries to drive into smart environments according to the new productive paradigm.

Last observation that leaves this work is that the challenge to adopt the new practices within industry 4.0 concept are a worldwide concern. There is to much to do to success in adopting the novel paradigm cross all latitudes and kind of industrial firm, with more emphasis in SMEs and emerging countries.

For further research agenda, there are some key issues that should be considered such as the role of innovation ecosystems to help upgrading processes towards smart practices in the industry, and the way innovation ecosystem can facilitate the search and validation of standards for the technological solutions around the smart manufacturing paradigm.

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