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Industry 4.0 base technologies and business models: a bibliometric analysis

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Abstract

Purpose – The objective of this study is to examine current business and management research on "Industry 4.0 base technologies" and "business models" to shed light on this vast literature and to point out future research agenda.
Design/methodology/approach – The authors conducted a bibliometric analysis of scientific publications based on 482 documents collected from the Scopus database and a co-citation analysis to provide an overview of business model studies related to Industry 4.0 base technologies. After that a qualitative analysis of the articles was also conducted to identify research trends and trajectories.
Findings – The results reveal the existence of five research themes: smart products (cluster 1); business model innovation (cluster 2); technological platforms (cluster 3); value creation and appropriation (cluster 4); and digital business models (cluster 5). A qualitative analysis of the articles was also conducted to identify research trends and trajectories.
Research limitations/implications – First, the dataset was collected through Scopus. The authors are aware that other databases, such as Web of Science, can be used to deepen the focus of quantitative bibliometric analysis. Second, the authors based this analysis on the Industry 4.0 base technologies identified by Frank *et al.* (2019). The authors recognize that Industry 4.0 comprises other technologies beyond IoT, cloud computing, big data and analytics.
Practical implications – Drawing on these analyses, the authors submit a useful baseline for developing Industry 4.0 base technologies and considering their implications for business models.
Originality/value – In this paper, the authors focus their attention on the relationship between technologies underlying the fourth industrial revolution, identified by Frank *et al.* (2019), and the business model, with a particular focus on the developments that have occurred over the last decade and the authors performed a bibliometric analysis to consider all the burgeoning literature on the topic.

Keywords Innovation, Business model, Technology, Bibliometric analysis, Industry 4.0
Paper type Research paper

1. Introduction

In recent years, the Fourth Industrial Revolution has become one of the most debated topics by academics and professionals in the field of technological innovation and advanced

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manufacturing (Chen *et al.*, 2021). Within this context, Industry 4.0 refers to a large set of technologies that are likely to influence companies, governments and society and include IoT, CPS, robots/human robot collaboration, additive manufacturing, AI, big data analytics, cloud computing, augmented reality and blockchain technologies (European Commission, 2016; Masood and Egger, 2019; Miller, 2018). In particular, these technologies allow to collect data in real-time, analyse them, providing useful information to the manufacturing system (Wang *et al.*, 2016). Among the plethora of digital technologies emerging within the fourth industrial revolution, Frank *et al.* (2019) highlight that "Industry 4.0 base technologies" are the ones that allow firms to develop new products and services through the creation of new concepts based on the cyber-physical system of Industry 4.0 (Lu, 2017). Industry 4.0 base technologies "provide connectivity and intelligence for front end technologies" (Frank *et al.*, 2019, p. 5).

The development and implementation of IoT, AI, machine learning, cloud computing and big data analytics indeed represent an opportunity for improving a firm's position in the market (Li *et al.*, 2020). In particular, these technologies determine opportunities for firms to improve their processes and products and to innovate their business models (BMs) by acting on different levels: as a back-office improvement instrument, as a new channel to provide the market with new products and services, and as a technological incentive for a change in the business model itself (Baden-Fuller and Haefliger, 2013). Additionally, the emergence of Industry 4.0 base technologies may oblige and/or allow firms to reshape their BMs (Ciampi *et al.*, 2021; Del Sarto *et al.*, 2021; Dijkman *et al.*, 2015), with a potential in terms of competitive opportunities. Many academics in fact advocate that Industry 4.0 base technologies influence the development of new BMs (Chen *et al.*, 2021).

In particular, there are two ways through which the adoption of Industry 4.0 base technologies may impact BM innovation (Baden-Fuller and Haefliger, 2013; Messeni Petruzzelli *et al.*, 2022). First, their adoption can lead firms to adapt their existing BMs. For example, Amazon and Zappos reshaped their BMs by adapting existing BMs to novel contexts (Del Sarto *et al.*, 2021; Nylén and Holmström, 2015). Second, the adoption of Industry 4.0 base technologies may facilitate the adoption of novel BMs. In fact, Industry 4.0 base technologies often change the rules of the game of value creation and capture, in particular by forcing companies to overhaul their existing BMs (Schaefer *et al.*, 2017).

However, despite the importance of these topics for both academics and managers, along with the increased attention paid to the fourth industrial revolution and its impact on BMs, the literature exploring this link is still fragmented and a comprehensive view of all the possible ways through which Industry 4.0 base technologies affect firms' BMs in the wake of this revolutionary change is not available (Cozzolino *et al.*, 2018; Foss and Saebi, 2018). Thus, in this paper, we focus our attention on the relationship between technologies underlying the fourth industrial revolution, identified by Frank *et al.* (2019), and the business model. We perform a bibliometric analysis to consider all the burgeoning literature on the topic with a particular focus on the developments that have occurred over the last decade.

Actually, Agostini and Nosella (2021) have addressed this issue. In particular, they merged two streams of literature (i.e. digital/Industry 4.0 technologies and BMs) and systematized this body of literature through a bibliometric literature review. Using the bibliographic coupling approach complemented with factor analysis and the content analysis of 285 articles collected, the authors identified four main research streams (i.e. digital technologies and business model innovation, digital strategy and BMs, digital platforms and BMs, and IoT, servitization, and BMs). This insight contributed to Industry 4.0 and BMs works highlighting the conceptualization of relevant constructs and integrating for the first time two streams of research whose relationship had not been explored yet in previous research.

Notwithstanding that, in our opinion, such an approach shows three weaknesses. First of all, we noticed that their research explores the relationship between all Industry 4.0 technologies and BM. While such an approach can be viewed as comprehensive, it does not appear to be sufficiently focused, since not all Industry 4.0 technologies equally facilitate the adoption of new business models (Müller *et al.*, 2018b).

In this regard, Frank *et al.* (2019) highlight that, among Industry 4.0 technologies, those that are base technologies, i.e., IoT, cloud services, big data and analytics, are more influential on firms' BMs than other Industry 4.0 technologies (for instance as they "provide connectivity and intelligence for front end technologies" (Frank *et al.*, 2019, p. 15)). Actually, this finding is also evident in the work by Agostini and Nosella (2021) since they argued that the stream of literature on Industry 4.0 and BMs is likely to branch out into streams that are more specific on big data, IOT, and cloud computing technologies. As such, many scholars advocate that IoT, cloud, big data and analytics have disrupted entire value chains, leading to the formation of new BMs and determining an explosion of scientific outputs on these topics (Del Sarto *et al.*, 2021; Ferrigno *et al.*, 2023). For the above reasons, we believe that a better approach to codifying the connection between Industry 4.0 technologies and BMs can be achieved by focussing solely on IoT, cloud services, big data and analytics.

Second, we observed that their articles' analysis stops in mid-2020, whereas, in the last three years, a very large number of studies has been published in the Industry 4.0 base technologies and business model domain, especially after Covid-19 (i.e. Clauss *et al.*, 2022; Narayanamurthy and Tortorella, 2021). Moreover, such a proliferation of studies has been reinforced by several special issues that have contributed to the progress of both research areas (for instance, Appio *et al.*, 2021; Di Minin *et al.*, 2021). As a net result, so many new studies have indeed impacted on the links between the two research areas, which need to be analysed and systematized. In fact, the clusters that result from merging works on Industry 4.0 base technologies with those focused on BMs might be different than those highlighted in their work.

Third, a detailed description of the research process used to support the findings by Agostini and Nosella (2021) was not available. In their study, the perimeter of the research field was not clearly specified since a comprehensive description of the most prominent investigated topics, as well as the most influential authors, institutions and countries selected in the survey is not provided. A bibliometric analysis is believed to represent an appropriate solution to achieve these objectives since it empowers scholars to identify a discipline's most influential studies and relevant scientific activities (Farrukh *et al.*, 2021; Zhao *et al.*, 2021). Therefore, in our article, we chose to offer some insights regarding the distribution of articles across the above-mentioned categories. More importantly, the two mentioned authors performed a coupling analysis, which is one of the most used bibliometric techniques applied to systematize the literature on two constructs in a specific field (Cucino *et al.*, 2021; Yoon *et al.*, 2019). On the other hand, it is widely acknowledged that co-citation analysis is advantageous for mapping the intellectual heritage of a particular field on the basis of high-impact publications (Yoon *et al.*, 2019) and this is why we chose to use it to complement the findings by Agostini and Nosella (2021). Furthermore, recent articles suggest that bibliometric techniques can be integrated with qualitative analyses (Trabucchi and Buganza, 2021). Accordingly, we also conduct a qualitative inspection of the articles to provide a more comprehensive overview of the nexus between Industry 4.0 base technologies and BMs works. More specifically, we analysed the articles with a qualitative approach to identify future research trajectories. Thus, our research aims to achieve a better understanding of the literature that associates the constructs of Industry 4.0 base technologies and BMs. More concretely, in this study we address two questions: How do the Industry 4.0 base technologies and BM streams of literature merge? What are the main research streams and fruitful paths for future research?

To tackle RQ1, we conducted a quantitative bibliometric analysis of 482 peer-reviewed articles, using co-citation analysis. The results of the co-citation analysis revealed that five thematic clusters emerge from bridging Industry 4.0 base technologies and business models literature: (1) Smart products; (2) Business model innovation; (3) Technological Platforms; (4) Value Creation and Appropriation; and (5) Digital business models.

To answer RQ2, the results have been integrated through a qualitative analysis. More specifically, the qualitative analysis highlights five trends consolidated in the literature on BMs and Industry 4.0 technology: (1) Digital Transformation; (2) Servitization; (3) Opportunities for SMEs; (4) Circular economy systems; and (5) Disruptive supply chain logistics.

The article is structured as follows. In Section 2, we discuss the importance of studying the nexus between Industry 4.0 base technologies and business model works. In Section 3, we outline an overview of the methods and data procedures used. In Section 4, we provide a descriptive analysis of the most cited articles and the most influential authors, including their institutions and countries. Moreover, we utilize VosViewer to perform a co-word analysis and a co-citation analysis to track the most relevant trends and themes and assess their evolution over time. In Section 5, we complement these findings through a qualitative analysis of the research trajectories that can be further investigated. Finally, in Section 6, we summarize the main implications and limitations of the article.

2. Theoretical background

2.1 The industry 4.0 base technology scenario

Industry 4.0., also defined as the "fourth industrial revolution", is a wave of innovation that is spreading forcefully and quickly in the production systems all over the world (Bauer *et al.*, 2015). The industrial revolution is characterized by the introduction of intelligent machines, interconnected and connected to the Internet, which allows complex analyses that otherwise would not have been possible (Agostini and Nosella, 2021; Kaggermann, 2015). Moreover, Industry 4.0 has been enabling firms to achieve greater productivity through shorter set-up times (Rocha *et al.*, 2019), reduced errors and machine downtime (El-Alfy and Mohammed, 2020), allowing them to move faster from prototype to mass production through new technologies (Mubarak and Petraite, 2020), and obtain better quality and less waste thanks to sensors that monitor production in real time (Bauer *et al.*, 2015).

Given its important results and huge potential in terms of improved productivity, many scholars have been paying renewed attention to firms' innovation processes and to the many different definitions of Industry 4.0 which have emerged since its launch and first implementation cases (Agostini and Nosella, 2021; Müller *et al.*, 2018b). Although many researchers have discussed a variegated set of digital technologies about Industry 4.0, what seems to be missing in the literature is a more careful analysis about a specific sub-set of these technologies, namely Industry 4.0 base technologies - (1) Internet of things, (2) cloud services, (3) big data, and (4) analytics - which are particularly important for firms' innovation processes. For example, Frank *et al.* (2019) defined them as "technologies that provide connectivity and intelligence for front-end technologies".

2.2 Business models innovation

The success of Industry 4.0 base technologies is often ascribed to the impact that these digital technologies, solutions, or technological improvements have on companies' production systems (Frank *et al.*, 2019). Big data, analytics, cloud services, and IoT have indeed a large impact on industry, while affecting the whole life cycle of the product, providing new ways of production and conducting businesses. In this regard, many academics believe that Industry 4.0 base technologies have a relevant influence on the development of new business models (Ciampi *et al.*, 2021; Chen *et al.*, 2021; Veile *et al.*, 2022).

2.3 Industry 4.0 base technology and business models

Despite the wide consensus about the importance of Industry 4.0 base technologies for business model research (Frank *et al.*, 2019), many scholars point out the need to better understand the impact of Industry 4.0 base technologies on BMs and the mechanisms through which this effect takes place (Shet and Pereira, 2021). Understanding this issue appears critical for at least two reasons. First, technologies such as IoT, cloud computing, big data and analytics, have disrupted entire value chains, leading to the formation of new BMs and determining - as a consequence - a strong increase in scientific production on this topic (Del Sarto *et al.*, 2021). Moreover, Industry 4.0 base technologies may determine the emergence of new BMs (Müller *et al.*, 2020). Second, many research fellows and practitioners are emphasizing that, with the advent of Industry 4.0, not only new BMs are emerging, but existing ones are reconfigured (Foss and Saebi, 2017, 2018). While initial studies of BMs explicitly recognize the central role of physical elements (Dasilva *et al.*, 2013), current and emerging forms of BMs are prominently based on the adoption of digital infrastructures (Warner and Wäger, 2019). Therefore, Industry 4.0 base technologies have raised renewed interests in the research related to BMs in the digital era (Ciampi *et al.*, 2021; Frank *et al.*, 2019; Veile *et al.*, 2022).

3. Methodology

To build our sample, we first selected papers using the Elsevier's Scopus database. Scopus is recognized as one of the most comprehensive databases covering peer-reviewed research in reputable journals (Caviggioli and Ughetto, 2019). Moreover, Scopus is a well-organized, indexed database of scientific production with the possibility of exporting metadata (Cobo *et al.*, 2011).

In particular, we chose a time period which extends the exercise made by Agostini and Nosella (2021). We then analysed the selected articles by conducting a co-citation analysis (Crupi *et al.*, 2021; Farrukh *et al.*, 2021), which is widely adopted in the literature to analyse past scientific publications (Miau and Yang, 2018; Yoon *et al.*, 2019).

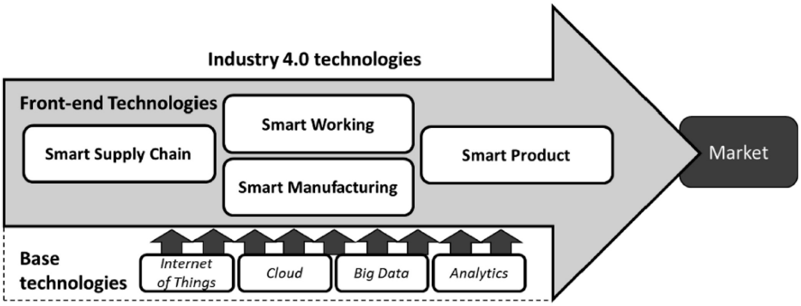
After this phase, in order to identify thematic clusters, we relied on normalized correlation measures. Following previous literature, we implemented measures of association based on information co-occurrence. Accordingly, we adopted VOSviewer 1.6.18 which uses the algorithm visualization of similarities (Yoon *et al.*, 2019). After identifying the clusters, we classified them by running the term frequency count and analysing the content of titles, abstracts, and keywords of the grouped publications. Moreover, we produced descriptive statistics by using the bibliometrix R package (Aria and Cuccurullo, 2017).

In the last step, we selected the articles which received the higher number of citations and the strongest link in each cluster, and we proceeded with a qualitative analysis of the full publication.

3.1 Sample selection and description

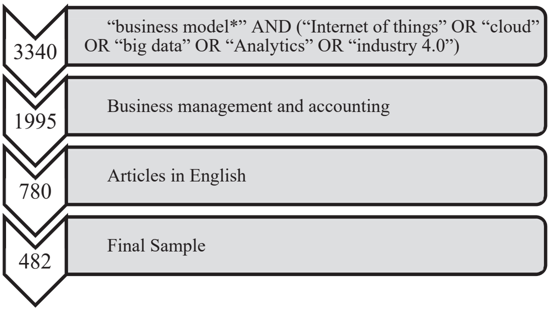
To identify publications in the Industry 4.0 and business model domains the following terms were considered: business model, Internet of things, cloud, big data, analytics, and Industry 4.0. We searched for these terms in titles, abstracts, and keywords of each article and used the * (wildcard character) to include plurals of each keyword. Moreover, we created and searched the following queries in the Scopus database: "business model*" AND ("Internet of things" OR "cloud" OR "big data" OR "Analytics" OR "industry 4.0"). To identify the correct keywords and target the Industry 4.0 domain, we followed Frank *et al.* (2019), who developed the theoretical framework of Industry 4.0 base technologies reported in Figure 1.

Finally, following previous studies (Xu *et al.*, 2018), we adopted several filters (Figure 2): (1) categories: "Business Management and Accounting"; (2) document type: "Articles in English". Finally, we started our analysis from 2011, since this is considered the year in which first contributions about Industry 4.0 have appeared.



Source(s): Frank *et al*. (2019)

Figure 1.
Theoretical framework of industry 4.0 base technologies



Source(s): Authors own creation

Figure 2.
A snapshot of articles search

After, we reviewed the full text of these papers to be sure that the focus of the analysis was the field of business model in Industry 4.0 and we identified 482 articles suitable for bibliometric analysis. Once the final sample of 482 papers was identified, we created an Excel workbook and we coded the content of each article by its author(s), journal title, subject area, investigated area, number of citations, subtopics, and methodologies (Petticrew, 2006).

4. Results

In Table 1 we reported descriptive statistics about the selected publications.

As expected, the relevant growth of articles focussing on the intersection between Industry 4.0 base technologies and BMs took place in 2011, the year in which the term Industry 4.0 was first introduced.

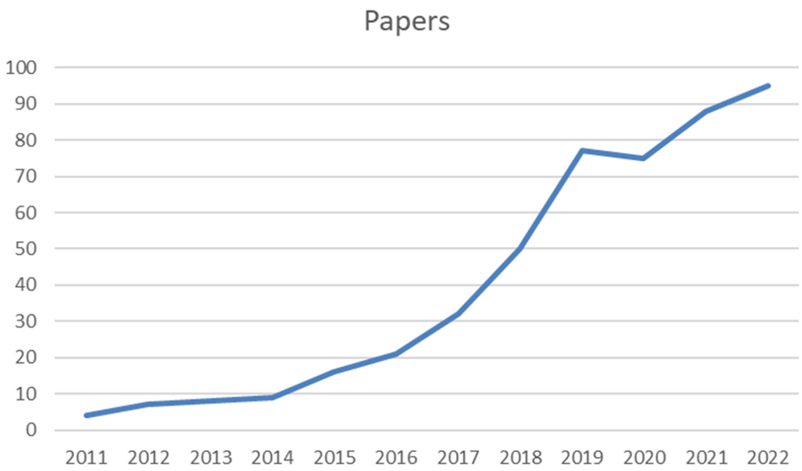
Starting from this year, in fact, we observe an increase of annual publications on the topic (Figure 3). This explosion reached its peak in 2019, confirming scholars' attention to this emerging topic, certainly due to the explosion of solutions pertaining to industry 4.0 and its base technologies.

Looking at the outlet of publications, many high-quality international journals have published articles on the topic (Figure 4). With regard to the most cited sources on this topic (Figure 5), the list is led by *Harvard Business Review, Long Range Planning, Strategic Management Journal, and Industrial Marketing Management*. However, if we consider both lists (most relevant and cited sources), we also note that the ranking is led by *International*

Table 1.
Descriptive analysis of our research strategy

Description	Results
No. of Documents	482
No. of sources	204
No. of Keywords Plus	1,058
No. of Author's Keywords	1,178
Search Period	2011:2022
Average Citation per document	18.86
No. of Authors	965

Source(s): Authors' own creation



Source(s): Authors own creation

Figure 3.
Annual scientific production

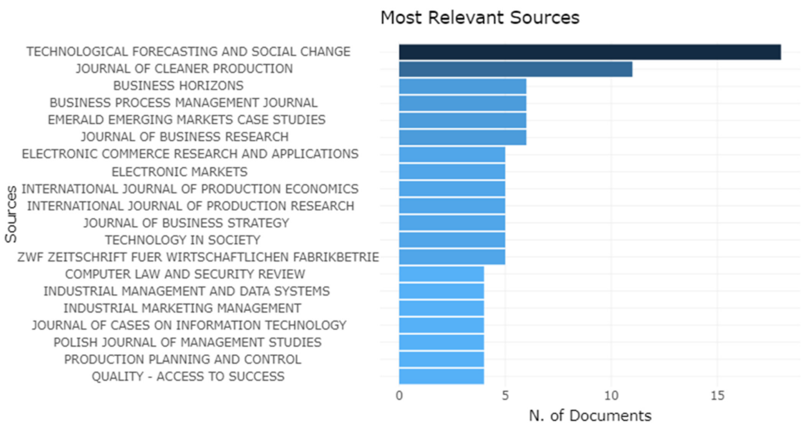


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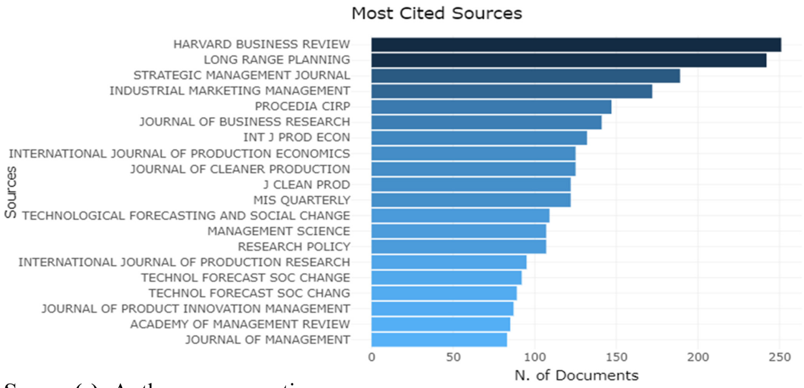
Figure 4.
Most relevant sources



Source(s): Authors own creation

Figure 5.
Most cited sources

Journal of Production Economics and *Journal of Business Research*, thereby indicating that these journals are among the top most relevant and cited journals investigating the relation between Industry 4.0 base technologies and BMs.

Figure 6 shows the results of the computations carried out by the bibliometrix Rpackage software to identify the trending topics within the Industry 4.0 and Business model research field. This analysis allows generating a map of the conceptual structure of a topic using the co-occurrences of words in a bibliographic collection (Aria and Cuccurullo, 2017). These words were defined by the "KeyWords Plus" software and are based on Scopus indexed keywords.

As Figure 7 and Table 2 show, the US is the leader with regard to publications, followed by China, Germany, UK, and Italy. According to Adedoyin *et al.* (2020), the primacy of the US in terms of the productivity of scientific articles can be related to the considerable investments that the country has planned to invest in infrastructure and ICTs from 2014 to 2025.

4.1 Thematic map

The thematic evolution of a scientific field can be quantified and visualized using co-word analysis (Cobo *et al.*, 2011). In our case, clusters of topics were obtained and plotted according to centrality and density indices (Cucino *et al.*, 2021) (Figure 8). The centrality index measures the intensity of the link of a cluster with other clusters. The density characterizes the strength of tie between clusters (Kipper *et al.*, 2020). Figure 8 shows an example of a strategic diagram with four categories of clusters: principal, secondary, crossroads, and isolated.

The co-wording analysis allowed us to identify ten clusters and classify them into the four main categories (Figure 9).

(1) Specialized themes (low centrality and high density):

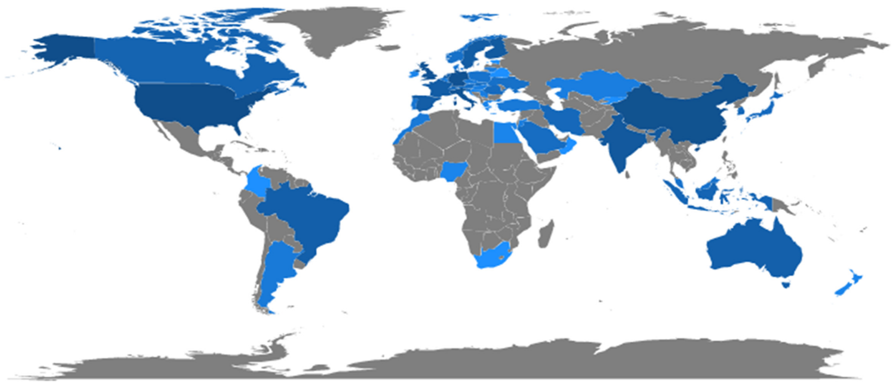
- Cluster 1: digital transformation (11), service industry (7), information and communication technology (6), qualitative analysis (6).

(2) Motor themes (high centrality and high density):

- Cluster 2: big data (23), new business models (17), commerce (14), sales (13), data mining (9)
- Cluster 3: competition (13), supply chains (10), competitive advantage (6), decision support systems (6), artificial intelligence (6).

Source(s): Authors own creation

Figure 6.
Trend topics



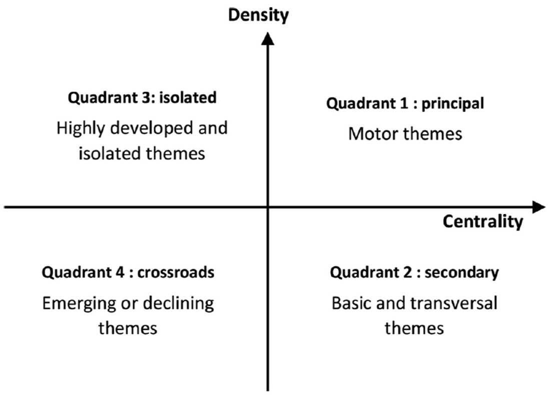
Source(s): Authors own creation

Figure 7. Country scientific production

Country	Papers	Frequency
US	70	12.4%
CHINA	55	9.7%
GERMANY	52	9.2%
UK	49	8.7%
ITALY	47	8.3%
INDIA	34	6.0%
FINLAND	30	5.3%
FRANCE	25	4.6%
SPAIN	24	4.4%

Source(s): Authors own creation

Table 2. Country, papers, and frequency



Source(s): Adapted from Cobo *et al*. (2011); Authors own creation

Figure 8. The strategic diagram

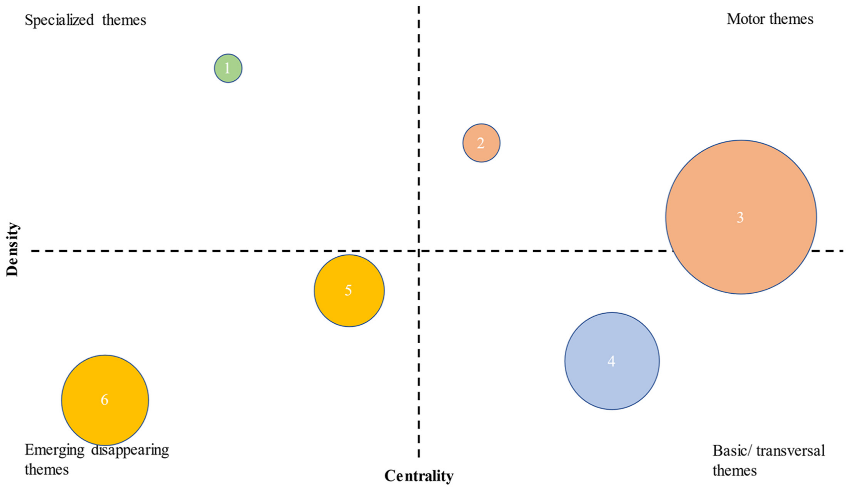


Figure 9.
Thematic clusters

Source(s): Authors own creation

(3) Basic themes (high centrality and low density)

- Cluster 4 Industry 4.0 (21), innovation (14), business model innovation (9), manufacture (9), sustainable development (8)

(4) Emerging/Disappearing themes (low centrality and low density):

- Cluster 5: cloud computing (13), business models (11), ecosystems (8), web services (6), distributed computer systems (5).
- Cluster 6: business modelling (31), Internet of things (29), Internet (13), digital business (4).

Starting from *specialized themes*, the papers included in cluster 1 deal with digital transformation and information and communication technologies. For instance, Warner and Wäger (2019) explored how incumbent firms in traditional industries build dynamic capabilities for digital transformation. They found that digital transformation is an ongoing process of using new digital technologies in everyday organizational life, which recognizes agility as the core mechanism for the strategic renewal of an organization's business model, collaborative approach, and eventually the culture. This theme presents high centrality and low density, which show that research in this field is still a niche.

Motor themes are characterized by high centrality and high density, meaning that around them a lot of literature is actually focused. Among the topics in this context, the most important one is represented by Big Data. For example, Faroukhi *et al.* (2020) provided an exhaustive and expanded Big Data Value Chain framework which helps firms handle Big Data monetization, making their processes entirely data-driven, supporting decision-making, and facilitating value co-creation.

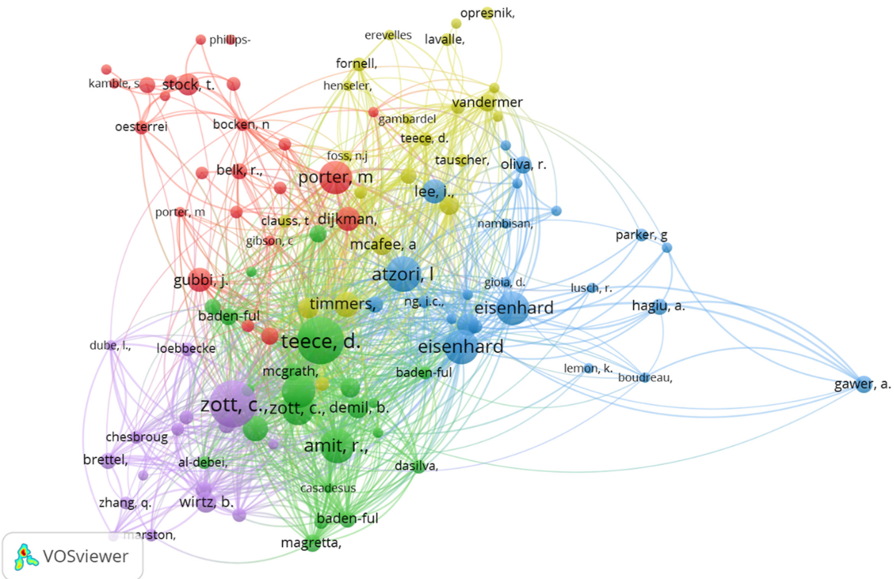
Basic themes are instead epitomized by high centrality and low-density measures and represent the main theoretical contributions in the field. More in detail, almost all the keywords of cluster 3 belong to the domain of Industry 4.0. In fact, even though the papers included in this cluster mainly leverage the theoretical contributions, they represent research topics that may become full motor themes in the next years.

4.2 The co-citation analysis

The Co-citation reveals the existence of five clusters that represent the current topics of interest (see Figure 10): (1) Smart products (red cluster); (2) Business model innovation (green cluster); (3) Technological platforms (blue cluster); (4) Value creation and appropriation (yellow cluster); and (5) Digital business models (purple cluster).

4.2.1 Red cluster: managing the transition from products to smart products. Studies within this cluster aim at investigating the impact that Industry 4.0 base technologies have on products and, more specifically, the transition from products to smart products, made possible by the addition of components such as RFID technologies (Moretti *et al.*, 2019). Moreover, ubiquitous sensing enabled by Wireless Sensor Network (WSN) technologies spawn across many areas of every daily life. The combination of the two technologies offers the ability to measure, infer and understand environmental indicators (Li *et al.*, 2020), from delicate ecologies and natural resources to urban environments (Gubbi *et al.*, 2013).

Smart, connected products offer expanding opportunities for new functionalities, far greater reliability, much higher product utilization, and capabilities that cut across and transcend traditional product boundaries (Li *et al.*, 2021; Raff *et al.*, 2020). The changing nature of products is also disrupting value chains, forcing companies to rethink nearly everything they do internally (Porter and Heppelmann, 2014). Moreover, smart and connected products raise a new set of strategic choices related to how value is created and captured, how the prodigious amount of new (and sensitive) data they generate is utilized and managed, how relationships with traditional business partners such as channels are redefined, and what role companies should play as industry boundaries are expanded (Dijkman *et al.*, 2015). Last but not least, some scholars have shown that the adoption of smart products has considerably increased in the post pandemic era (Agarwal *et al.*, 2022; Narayanamurthy and Tortorella, 2021).



Source(s): Authors own creation

Figure 10.
The co-citation analysis

4.2.2 Green cluster: unlocking the potential of business model innovation. According to numerous scholars, an important source of superior competitive advantage is represented by an innovative business model (Baden-fuller and Haefliger, 2013). For this reason, firms must continuously seek business model innovation instead of focussing only on product innovation. Studies grouped in this cluster describe the importance of business model innovation in unlocking the potential of Industry 4.0 (Foss and Saebi, 2017). This set of studies, in particular, points to the importance of innovating the business model to achieve sustainable competitive advantage. In particular, Chesbrough and Rosenbloom (2002) explored the role of the business model in capturing value from technology, pointing out that a successful business model unlocks latent value from technology, an aspect that is crucial for firms aiming at implementing Industry 4.0 base technologies. Within this vein, Zott and Amit (2010) conceptualized the business model as a system of interdependent activities, suggesting that firms that want to implement Industry 4.0 base technologies need to act on a bundle of activities that are intertwined with each other and which contribute to the definition of a successful business model. This approach may require a shift in value proposition from solely giving advice or supporting information technology implementation to providing end-to-end digital solutions (Tavoletti *et al.*, 2021).

Lastly, Clauss *et al.* (2022) have shown that SMEs respond to Covid-19 crisis via temporary business model innovation. Using a multiple case study approach based on five SMEs in Austria, Germany, and Liechtenstein, the authors found that temporary business model innovation is a new form of business model innovation that adds value to firms and create new revenue streams.

4.2.3 Blue cluster: the rise of technological platforms. The rise of a plethora of innovative and powerful digital technologies is reframing the ideas of both innovation and entrepreneurship (Cutolo and Kenney, 2019). Studies within this cluster focus on the impact that the massive adoption of these technologies has on businesses due to the change that platformization of increasing parts of the economy brings (Kenney *et al.*, 2019). Technological platforms are changing the environment in which many firms and entire industries operate. Until recently, the entrepreneurship and business strategy literature paid little attention to the impact these platforms will have on business (Nambisan *et al.*, 2019; Veile *et al.*, 2022). Research and theoretical frameworks are only now recognizing the fundamental differences between traditional and platform-dependent businesses. This is surprising, since almost every day, new instances of how platform companies exert power over their ecosystem members are reported in the media – an industry that is itself struggling with the implications of the platform economy (Kenney and Zysman, 2016). Platforms are dependent upon attracting complementors to their ecosystems (Gawer and Cusumano, 2014). Platforms and their ecosystems are gaining attention because of their contradictory effects (Hagiu and Wright, 2015; Trabucchi and Buganza, 2021). On one hand, they facilitate entrepreneurship by creating far larger markets (Parker and Van Alstyne, 2005). On the other hand, the panoptic power of platforms places entrepreneurs into a situation within which they are vulnerable and dependent upon the goals of the platform, which is, not surprisingly, the maximization of its income (Cutolo and Kenney, 2019).

4.2.4 Yellow cluster: balancing value creation and appropriation. The emergence of the new paradigm of Industry 4.0 has led to new ways of creating value (Kiel *et al.*, 2017; Veile *et al.*, 2022). New technologies, and in particular their combination, may help firms to explore new opportunities, thus creating new revenue streams which may lead to value creation (Ferrigno *et al.*, 2022b; McAfee *et al.*, 2012). In fact, value is created when an action is taken whose benefits are greater than its costs or when the opposite situation is prevented from occurring. However, the concept of value creation alone is not sufficient to explain how firms make profits (Amit and Zott, 2012; Cappa *et al.*, 2021). The benefits, indeed, are measured on the consumer's side, albeit they belong to the firm's side. Accordingly, the concept of value capture has been investigated. The selling price determines the amount of value that is “captured” by a firm and that contributes to its profits (Clauss, 2017). The two concepts are strongly intertwined with each other, and firms need to balance them, especially in dynamic and evolving markets in which new technologies appear (Barton and Court, 2012). When evolving markets are highly competitive one must increase profits through value creation (Chesbrough *et al.*, 2018). In this regard, Cappa *et al.* (2021) used the resource-based view and three dimensions of big data (i.e. volume, variety, and veracity) to understand the circumstances in which firms can benefit via value creation and/or value capture. Their findings indicate that, since big data variety moderates the negative effects of big data volume, simultaneous high values of volume and variety allow firms to create value that positively affects their performance. Moreover, high levels of veracity are correlated to firms benefiting from big data via value capture.

4.2.5 Purple cluster: implication of digital business models. For any business, either large or small, innovation (technology in particular) is the decisive factor for its competitiveness (Zott *et al.*, 2011). After all, the entrepreneur, by definition, must always be innovative if he/she wants to persist in the market so that the constant adaptation of his business model becomes essential (Kraus *et al.*, 2018, 2022). Today, innovation may not produce the desired effects if it does not correspond to a business model capable of effectively exploiting it and configuring an offer commensurate with the needs of customers, suppliers, and business partners (Cozzolino *et al.*, 2018). In a market that is increasingly complex and dependent on a growing number of factors, the critical analysis of the activity in relation to the production objectives, the company organization, the use of resources and marketing are a necessity that cannot be postponed, particularly due to the advent of Industry 4.0 (Brettel *et al.*, 2017; Ferrigno *et al.*, 2022a; Tavoletti *et al.*, 2021). Novelties often intimidate and force considerable efforts in terms of time, financial means, and personnel to be able to commercially exploit a new technology (Narayanamurthy and Tortorella, 2021; Zott and Amit, 2013).

5. Setting the research avenues through a qualitative analysis

Besides identifying the five above-discussed clusters that represent the current topics of interest emerging from works on Industry 4.0 base technologies and BMs, our article aims to discuss the research avenues that can be investigated by future studies. To achieve this aim, in this section, we integrate the findings of the co-citation analysis by performing a qualitative analysis of some of the newest and mostly cited contributions in the domain of Industry 4.0 base technologies and BMs. This analysis allows us to promote a deeper understanding of the connections between Industry 4.0 base technologies and BMs and, more importantly, a set of interesting and increasingly important research trajectories in the selected research field.

In particular, starting from the top cited articles derived from the bibliometric analysis, the authors read 35 articles separately and identified future research areas relevant to the topic in subsequent meetings.

5.1 Research avenue #1: digital transformation

An increasing field of study is that of digital transformation, the process of integrating digital technologies into all aspects of the business, a process that involves substantial changes in technology, culture, operations, and value generation (Hartmann *et al.*, 2016). Businesses are rapidly replacing their traditional interactions with digital experiences powered by technological advances. In many cases, this happens not because firms choose transformation, but because they have to transform to survive (Warner and Wäger, 2019).

The market expects firms offering efficient digital experiences, and those that do not adapt to this new digital consumer model is doomed to failure (Wirtz *et al.*, 2019).

Recent studies have shown that, to make the most of emerging technologies and their rapid expansion in human activities (Cucino *et al.*, 2022), firms must know how to reinvent themselves, often radically, transforming all their models and processes (Dąbrowska *et al.*, 2022). In this regard, many scholars have emphasized that shifting attention to the corporate edge and the more agile data centers that support it can enable digital transformation (Bouwman *et al.*, 2018; Kraus *et al.*, 2022). Moreover, abandoning legacy technology, the maintenance of which can be costly, and changing the corporate culture may be helpful to support the acceleration resulting from digital transformation (Morabito, 2015).

5.2 Research avenue #2: servitization

The Industry 4.0 paradigm is also changing the dynamics of the production environment (Sung, 2018), with smart manufacturing increasingly linked to the concept of servitization (Gretzel *et al.*, 2015). From a methodological point of view, the so-called servitization implies that companies specialized in the production of goods also offer additional services in the post-sale phase. The innovative, and “smart” nature of this mechanism derives from the ability to draw on the usage data of the goods sold, to analyse them in advance and securely thanks to modern cutting-edge technologies such as Big Data, Cybersecurity, and Blockchain (Saarikko *et al.*, 2017). In this way, through the implementation of Digital Enabler Technologies, traditional processes are undermined which, for example, in maintenance are limited to a reactive service or a schedule of standardized periodic interventions (Favoretto *et al.*, 2022; Ng and Wakenshaw, 2017). It is manufacturers themselves who, within servitization strategies, adopt condition monitoring actions about the conditions of the machinery or the whole system, in order to apply Predictive Maintenance that allows the operator to constantly monitor systems and processes and intervene in real-time in case of malfunctions (Nittala *et al.*, 2021).

5.3 Research avenue #3: opportunities for SMEs

Digitalization also offers companies new opportunities to participate in the digital revolution of production. Emerging digital technologies, such as big data analytics, artificial intelligence, and 3D printing, allow for greater product differentiation, mass customization, more integrated distribution systems and, overall, new BMs, which shorten times to reach the markets (Moeuf *et al.*, 2018).

In this context, some scholars advocate that the development of Industry 4.0 base technologies has paved a fertile ground of opportunities for SMEs (Eggers, 2020). Industry 4.0 base technologies favour SMEs’ access to skills, through better professional recruitment sites, online access to external skills, including for specific tasks, or by facilitating sharing of knowledge with other partners (Del Sarto *et al.*, 2022), through the knowledge partner (Moeuf *et al.*, 2020), especially after Covid-19 outbreaks (Clauss *et al.*, 2022). Another opportunity resides in SMEs’ integration into markets and global value chains, through the creation of effective mechanisms to reduce the disadvantages associated with the size of companies in international trade (Crick *et al.*, 2023), for example by reducing the absolute costs associated with transport and customs operations (Arnold *et al.*, 2016; Garzella *et al.*, 2021).

To benefit from these opportunities that emerge from Industry 4.0 base technologies, SMEs should exploit all possible resources without limiting themselves to the ones related to such new technologies (Bienhaus and Haddud, 2018). Also, SMEs must avoid adopting Industry 4.0 concepts only for monitoring industrial processes and also find real applications in the field of production planning (Müller *et al.*, 2018a).

5.4 Research avenue #4: circular economy systems

The recent highly cited papers in the research domain of Industry 4.0 base technologies and BMs suggest, not surprisingly, many research directions that are related to the circular economy (Rosa *et al.*, 2020; Yu *et al.*, 2022). Circular Economy constitutes a new emerging economic paradigm capable of replacing production models centred on a linear vision, aiming at reducing waste and a radical rethinking in the conception of products and their use over time (Jaaron and Backhouse, 2021). According to many scholars, this is a very ambitious challenge for both the production system and society as a whole, as it requires the adoption of activities and production and consumption processes that are sustainable and capable of consciously and efficiently managing the resources of our planet (Lardo *et al.*, 2020). The transition towards a circular economy can easily be favoured by the development of digital technologies connected to Industry 4.0, or the fourth industrial phase we are currently going through, based on the technological mix of robotics, sensors, connections to the Network, programming and opportunities of the internet of Things (IoT) (Alqahtani *et al.*, 2019). These technologies open up new spaces for innovation towards more sustainable design and production, as well as for the creation of processes that make it possible to track the consumption of resources and the use of products (Braz and de Mello, 2022). The connection between the Digital and the Circular Economy could change the labour market forever, both from the point of view of processes and resources and that of the people and skills implemented (Alcayaga *et al.*, 2019). Digital represents the essential fulcrum for the development of activities linked to the entire circular ecosystem as the internet of Things is able to monitor the life cycles of a product, data analysis can make the quantity of goods produced sustainable and thanks to the purchase and consumption insights it is possible to meet the needs of the consumer in the production phase, avoiding waste and overproduction (Jabbour *et al.*, 2019).

5.5 Research avenue #5: disruptive supply chain logistics

Industry 4.0 offers an important opportunity for the evolution of the supply chain in terms of speed, scalability, AI, cloud computing, connectivity, and interconnection (Birkel and Müller, 2021; Gebhardt *et al.*, 2022; Khanagha *et al.*, 2014). In some companies, the results of the application of Industry 4.0 base technologies to Supply Chain processes are already visible (Zhou *et al.*, 2015). Automated processes and Cloud connections have already been adopted, but in the future the focus will be on the implementation of robots, artificial intelligence, and big data (Baghdadi, 2013; Chiarini, 2021). Another change in the context of Industry 4.0 is represented by the evolutionary characteristics of the products: connected, intelligent and proactive (Birkel and Müller, 2021; Prause and Atari, 2017). Industry 4.0 products receive and transmit data in real-time; through this information, companies develop new BMs and services associated with goods (Yu *et al.*, 2017). This "real-time" data collection gives companies the competitive advantage of offering customers different payment methods based on the actual use or performance of the asset (Dewald and Bowen, 2010; Gebhardt *et al.*, 2022). This 4.0 context, therefore, favours a continuous and constant evolution of companies to remain competitive. In fact, digitalization in companies is an increasingly growing phenomenon given the strong pressure from suppliers, partners, the market, and competitors. By adopting 4.0 technologies, companies can generate improvements in the processes and products offered (Chiarini, 2021; DaSilva *et al.*, 2013; Gebhardt *et al.*, 2022).

6. Conclusions, limitations, and further developments

This study has provided an overview of the impact, trends, and trajectories in the business and management literature concerning Industry 4.0 base technologies and BMs. We used several bibliometric analysis techniques (namely co-word and co-citation analysis) to assess the scholarly scientific production on the interaction between these two important topics and we also tracked its intellectual structure. Such techniques enabled us to capture the productivity ratio (e.g. total publication) as well as the relevance (e.g. the total number of citations or citations per year) of authors, journals, and countries. It was shown that Technological Forecasting and Social Change has been the journal which has been more active in investigating the relation between Industry 4.0 base technologies and BMs. Moreover, Harvard Business Review is the most-cited journal on this topic. Also, the International Journal of Production Economics is one of the top most relevant and cited journals investigating the relation between Industry 4.0 base technologies and BMs.

To answer RQ1 (how do the Industry 4.0 base technologies and BM streams of literature merge?), we conducted a co-citation analysis between Industry 4.0 base technologies and BM. The results of this analysis revealed the existence of five clusters of interest: (1) Smart products; (2) Business model innovation; (3) Technological Platforms; (4) Value Creation and Appropriation; and (5) Digital business models. These results partly confirm what has been found from previous studies that have conducted similar research through other bibliometric techniques such as coupling analysis (Agostini and Nosella, 2021). More specifically, some clusters (i.e. business model innovation, technological platform, and digital business models) still appear to be relevant important themes; rather, other clusters (i.e. value creation and appropriation and smart products) appear as new important topics. A plausible explanation of this partial divergence of results can be synthesized in two important arguments. First, Agostini and Nosella (2021) examined works up to mid-2020; instead, our analysis also includes articles published in the last three years. In this sense, our research complements their findings as it offers a more updated and comprehensive review. This is especially important if we consider the massive amount of publications and special issues that aroused after Covid-19. Second, as we discussed in the first sections of the paper, our research is focused on bridging business model literature with a specific corpus of Industry 4.0 research domain, namely Industry 4.0 base technologies. Therefore, the fact that for instance “smart products” emerges as an additional cluster compared to Agostini and Nosella (2021) is not surprising if we consider the features that make Industry 4.0 base technologies (i.e. IoT, cloud services, big data, and analytics) different from front end Industry 4.0 base technologies (Frank *et al.*, 2019).

To answer RQ2 (what are the main research streams and fruitful paths for future research?), instead, we integrated the findings emerging from the bibliometric techniques by performing a qualitative analysis of some of the most recent and highly cited articles that arose from merging works on Industry 4.0 base technologies and BMs. This approach allowed us to identify a menu of interesting findings for developing a comprehensive understanding of the extant and future research on the topics. More specifically, we were able to identify the following research trajectories: (1) Digital Transformation; (2) Servitization; (3) Opportunities for SMEs; (4) Circular economy systems; and (5) Disruptive supply chain logistics.

Taken together, these findings lead us to offer a possibly useful research baseline for both scholars and practitioners interested in exploring this flourishing area of research. In particular, our study contributes to the literature by putting an order to the huge amount of published papers in a systematic way, and by providing useful categorizations which may act as a base for the future flourishing of studies in an important field. Furthermore, scholars may take advantage of the findings of this study to better address future studies, considering the proposed avenues for future research. In parallel, policymakers and practitioners may leverage this study to revamp the value proposition of a firm’s BMs based on the development of Industry 4.0 technologies.

Moreover, the paper’s findings have several managerial implications for firms that are interested in implementing Industry 4.0 base technologies. First, the paper highlights the importance of business model innovation in firms that aim to take advantage of these technologies. As such, the findings of this study suggests that firms should focus on developing digital business models that are adapted to the new technological landscape, create value for customers and appropriate value for themselves.

Second, the paper emphasizes the need for firms to invest in technological platforms that support the implementation of these technologies. As such, investments in IoT devices, cloud computing infrastructure, and big data analytics tools may help firms to gather, analyse, and act on data in real time.

Third, the paper also suggests that firms should focus on developing smart products that can communicate with each other and with the wider technological ecosystem. This could involve embedding sensors and other IoT devices into products to gather data on their usage and performance as well as using these data to improve the products over time.

Overall, the paper suggests that firms that want to take advantage of Industry 4.0 base technologies need to adopt a holistic approach that involves investing in technological platforms, developing smart products, and innovating their business models. By doing so, they can create value for customers, appropriate value for themselves, and stay ahead of the competition in the rapidly evolving technological landscape.

Nevertheless, some limitations do exist, some of which may represent a fertile soil for future work for academics and practitioners. First, the dataset was collected through Scopus. We are aware that other databases, such as Web of Science, can be used to deepen the focus of quantitative bibliometric analysis. Second, we based our analysis on the Industry 4.0 base technologies identified by Frank *et al.* (2019). We recognize that Industry 4.0 comprises other technologies beyond IoT, cloud computing, big data and analytics. Hence, an interesting research question for future work is to provide a more comprehensive assessment of the impact of Industry 4.0 base technologies on BMs, thereby including other, albeit less influential, technologies of Industry 4.0., such as 3D printing, cybersecurity, etc (Benitez *et al.*, 2020; Garzella *et al.*, 2021).

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