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OPEN INNOVATION: A RESEARCH FRAMEWORK AND CASE STUDY OF HUAWEI

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Abstract. Open innovation (OI) has received significant attention from practices and theories over the past decades. This paper investigates the role of OI and personalized patterns in firms at home and abroad, and then measures the risks involved. Firstly, this paper reviews the definition of OI, the business model innovation characteristics, and the facing problems in practice. Based on the existing literature, we illustrate the openness and challenges of business OI. By introducing bibliometrics, this paper presents a whole research framework. Based on keywords co-occurrence analysis and clustering analysis, we locate the current research hotspots and potential research opportunities from a comprehensive perspective. According to the analysis results, five clusters are obtained, including resource management and value creation; collective innovation and form sustainability; innovation management, intellectual property management, and cross-border cooperation; knowledge management and knowledge sharing; innovation ecosystem, big data, and policy-level innovation. Taking Huawei as an example, its typical business OI model is studied from the perspectives of organizational, project-related, marketing and consumer-based, and summaries the facing challenges and risks. We illustrate its financial performance, innovation performance, and development prospects. We found that, during the implementation of OI practical activities and theoretical exploration, the risks and opportunities facing small and medium-sized enterprises (SMEs) are multiple dimensional.

Keywords: open innovation, bibliometrics, co-occurrence analysis, clustering, business model risks.

JEL Classification: O32, O36.

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Introduction

Open innovation (OI) is to open the traditional closed innovation model of enterprise and introduce external innovation capabilities. It is an innovation model and was first provided by Henry W. Chesbrough in 2003 (Chesbrough, 2003a). Under OI, companies can and should borrow external research capabilities just like using internal research capabilities. When expecting to develop technologies and products, they can use their channels and external channels to jointly expand market innovation. The theory emphasizes that enterprises purposefully allow knowledge to flow in and out to accelerate their internal innovation, and highlights the importance of external knowledge to the enterprises' innovation process (Chesbrough, 2003b, 2003c). Now, OI has become an innovation mechanism commonly adopted by leading companies.

With the rapid economic growth and increasingly fierce social competition, it is difficult for enterprises to adapt to market demand and corporate competition only relying on internal resources to conduct high-cost innovation activities. Under this circumstance, OI is gradually becoming the dominant mode of enterprise innovation. That is, they elevate the role of external creativity and external marketization channels to the same important position as that of internal ones (Jin et al., 2010; Jang et al., 2017). The internal and external resources can be balanced to innovate, which not only rests the innovation on the operation of the traditional product but also seeks the suitable business models to turn innovative ideas into real products and profits as soon as possible.

OI can expand the knowledge resource of companies, provide more innovation options and make more flexible innovation investments. Besides, it can also shorten the time to market for new products, improve the probability of innovation success, and reduce the risk and uncertainty (Chen & Chen, 2005). Thus, with the increasing development of information technology, to maintain and enhance the core competitiveness, OI has been the prior choice of business innovation. Theoretically, the significance of OI includes the following four aspects: (1) reduce costs, shorten the cycle and improve competitiveness; (2) reduce leakage risk of research results and increase revenue; (3) accelerate the speed of innovation, increase the success rate, market share and influence; (4) promote the development of the main business[1].

However, apart from the advantages of OI and the value it brings to the enterprise, challenges still exist (Calof et al., 2018; McGahan et al., 2021; Saguy & Sirotinskaya, 2014; Ollila & Elmquist, 2011; Salter et al., 2014; Nakagaki et al., 2012; Van de Vrande et al., 2009). That is, we need to fully understand the limits of OI based on the existing business practices and theories. Specifically, for big companies, such as IBM, P&G and Cisco, to expand the advantages in reducing the innovation costs and maintain a leading position in the innovation results, they can fully use the external innovation resources to develop products. Also, their research results that were put on hold for a long time and did not produce economic benefits are sold to third parties or used to attract venture capital institutions to set up a new company. Openness means more risks. Due to the large number of partners, there is competition for core network dominance. Besides, the capabilities of innovation participants

[1] https://wiki.mbalib.com/wiki/%E5%BC%80%E6%94%BE%E5%BC%8F%E5%88%9B%E6%96%B0

and coordinators are uncertain. Most of the small and medium-sized enterprises (SMEs) with weak innovation capabilities at home and abroad do not have enough opportunities to choose a wide range of external partners. There are not many innovative results that can be exchanged and shared. That is, they either cannot obtain vested benefits or lose many partners due to improper management (Saguy & Sirotinskaya, 2014; Van de Vrande et al., 2009).

By reviewing the existing research and applications in business model (Harun & Zainol, 2018; Wang, 2016; Yun et al., 2016; Davis et al., 2015), this paper reveals the current development characteristics of OI. Taking the advantages of bibliometrics, the keywords co-occurrence analysis and clustering analysis (Li & Xu, 2021; Li et al., 2020; Wang et al., 2020, 2021; Yu et al., 2017, 2018; Laengle et al., 2017) are introduced. The complete publications in the field of OI are exported from the Web of Science Core Collection. The analysis results are presented according to science mapping analysis using VOSviewer, CiteSpace and Science of Science (Sci2) tools (Chen, 2006; Stopar & Bartol, 2019; Van Eck & Waltman, 2010; Zou et al., 2018). Furthermore, the important research sub-fields are classified. Next, a case study is used to analyze the typical business mechanism to fully understand the current challenges and limits of OI. The risks of different types of companies in achieving OI are summarized. Finally, this paper heralds new challenges in practices and theory research. It is designed to warn companies, especially SMEs, what they need to pay attention to when implementing OI strategies in the future.

The rest of this paper is organized as follows: Section 1 reviews the literature, related to the definition of OI, individual strategies with the business model, the risks, and limits in recent years. Then, the research framework of this paper is illustrated. By introducing bibliometrics, Section 2 summarizes the current research hotspots and the main research sub-fields in the field of OI, based on the keywords co-occurrence, clustering analysis, and burst detection analysis. Combining with the typical practice case, the case analysis is presented in Section 3. According to the national condition in China, the further discussion is investigated in Section 4, which is related to the facing challenges and risks, and opportunities of OI. Then, some conclusions end this paper.

1. Literature review and research framework

1.1. The definition of OI

The definition of OI is a research product derived from the industrial R&D approach and science technology in economic productivity (Chandler, 1977; Freeman, 1982; Randhawa et al., 2016). OI was first defined in 2003 by Henry W. Chesbrough as a new requirement for organizing innovation. Chesbrough defined OI as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Marcel et al., 2019; Chesbrough, 2003a, 2003b, 2003c, 2004; Wang et al., 2009). The main idea behind OI was that firms can and should apply external ideas and resources as well as that of internal when they want to advance their innovation process (Chesbrough, 2006a, 2006b; Chiaromonte, 2006; Gassmann & Reepmeyer, 2005; Gaule, 2006; West & Bogers, 2017). There are disparate definitions and ambiguous theorization in the field of OI. For example, Trott and Hartmann (2009) criticized OI as "old wine in new bottles".

Since the OI paradigm was provided, organizational boundaries are no longer closed, and the position of innovation has gradually moved to the relational system related to external partners (Bogers & West, 2012; Zhang et al., 2021; Chen et al., 2021). West and Bogers (2014) emphasized the importance of external sources and profit from those innovations. In addition, they suggested clarifying the role of the business model. Chesbrough and Bogers (2014) redefined OI as a distributed and across organizational boundaries innovation process based on purposively managed knowledge flows. The process applies pecuniary and non-pecuniary mechanisms based on the organization's business model (Hidalgo & Palomares, 2021; Ghafoor et al., 2022).

The traditional innovation mechanism is closed and highly centralized, which is internally focused logic (Chesbrough, 2003a; Wang et al., 2009). That is, most of the research work is finished by the company itself. The company invests resources and advanced equipment in the internal research room. Also, the company is responsible for the generation, development, manufacturing, and marketing of innovative knowledge and ideas. Compared with the closed innovation mechanisms, the innovation concept and practice of OI are significantly different. It is to balance and coordinate the internal and external resources. While placing innovation goals on traditional product operations, companies actively seek out appropriate business models such as external technology partnerships, strategic alliances, or venture capital to turn commercial innovation ideas into reality while forming industrialization. In summary, it has the characteristics of openness, dynamics, and knowledge sharing (West & Bogers, 2014). Figure 1 illustrates the flow charts of traditional closed innovation and OI mechanisms.

1.2. The individual OI strategies with the business model

Since OI was introduced, scholars have started constantly research and expanded this research field by covering a wide variety of issues, from the human side (Ahn et al., 2017; Bogers et al., 2018) to firm-level characteristics (Bagherzadeh et al., 2021; Antons et al., 2016; Randhawa et al., 2016) to project-level attributes (Du et al., 2014; Kim et al., 2015) to platforms and ecosystems (Gawer & Cusumano, 2014; Holgersson et al., 2018) to public administration and societal issues (Ahn et al., 2019; Schmidthuber et al., 2019). Figure 2 shows the three main phases that an enterprise's OI model needs to go through, including forming short-term impact and rapid victory; building basic capabilities; establishing sustainable advantages. From the perspective of the whole process, there are two key technologies, i.e., effective partner management and development capabilities, OI culture and innovation ability training. West and Bogers (2014) gave a four-phase process model for leveraging external sources of innovation, including obtaining, integrating, commercializing external innovation, and interaction between the firm and its collaborators (as shown in Figure 3). The key to the success of OI is an effective business model. It is regarded as an intermediary structure between technology and economic value (Chesbrough & Rosenbloom, 2002). This is the only way to achieve success in innovation.

OI involves not only the acquisition and use of external resources, but also the use of internal knowledge (R&D and marketing) (Denicolai et al., 2016). In the business model category, the value network is the most important link (Bogers & West, 2012). It equips with

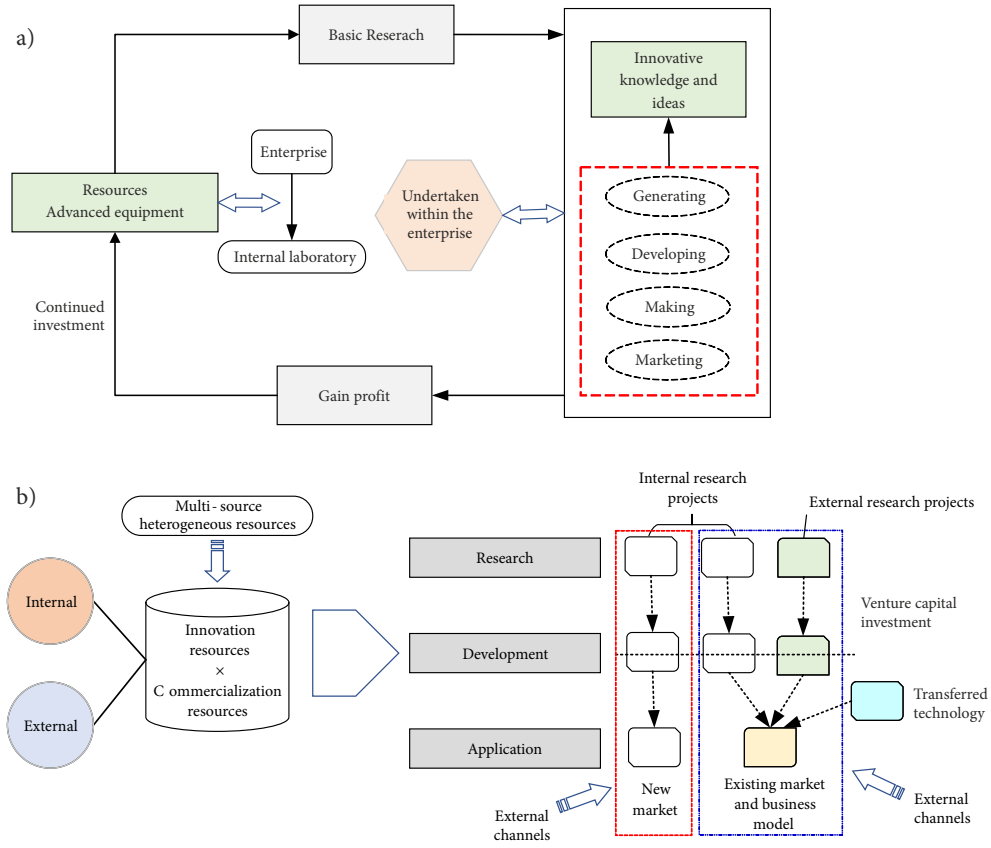

Figure 1. The traditional closed innovation and OI mechanisms:
a – the traditional closed innovation mechanism; b – the OI mechanism

the advantages of weakening the boundary between the company and the external innovation environment, paying more attention to the cultivation of core capabilities. In theory, an effective value network can achieve information sharing, rationalize the allocation of innovation resources, reduce enterprise innovation risks, and accelerate the industrialization of innovation results.

With the rise of the Internet, business model research has gradually become a hotspot. In the existing literature, scholars have conducted a series of studies on business model innovation in the context of OI. Initially, Chesbrough (2003a) held that a business model encompasses six roles, including articulating the value proposition; identifying a market segment; defining the structure of the value chain; specifying the revenue generation mechanisms for the firm; estimating the cost structure and profit potential of producing the offering; describing the position of the firm within the value network; formulating the competitive strategy. Besides, he argued that the business model innovation is not limited to searching for new technologies and companies should be more open to external ideas and paths (Chesbrough, 2006b). A business model framework was provided, including six types of business models. The business model innovation gap was pointed out (Chesbrough, 2007). Then, Venkatraman

and Henderson (2008) presented a business model innovation framework along two axes, i.e., value creation approach and scope of relationships in the network. The model is a dynamic and evolving process. Wang et al. (2009) presented a conceptual framework for business model innovation, which identified the origins and possibilities of business model innovation (BMI) under the environment of OI. A business model consists of a set of organizational and strategic solutions. Based on these solutions, firms organize their resources to balance the benefits against the external competition (Zott et al., 2011; Pisano et al., 2015). Different business models can promote corporate transformation to develop new value propositions for customers (Kavadias et al., 2016; Santoro et al., 2020). Abdulkader et al. (2020) gave a new theoretical framework rooted in the existing literature in the area of business process management, business strategy, and BMI. Carayannis et al. (2021) proposed an integrated framework for social business models.

For the previous research, several frameworks and roles on OI of the business model have been studied. For those typical business model companies with good OI applications, as well as failure cases, the existing studies also combine case analysis to explore the reasons, that is, the advantages and limitations of the personalized innovation mechanisms. For example,

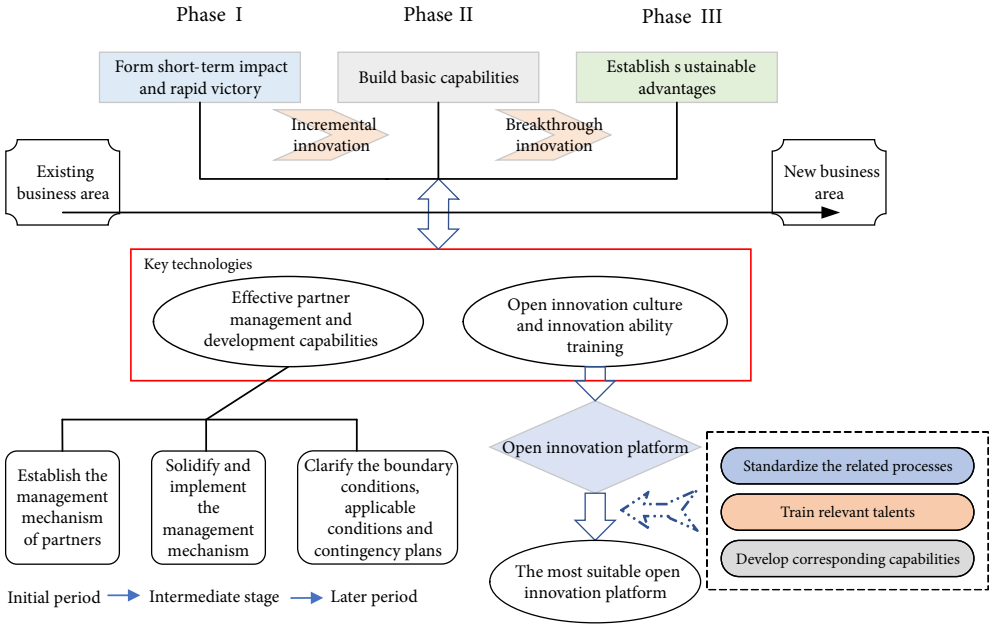

Figure 2. The main phases and key technologies of OI

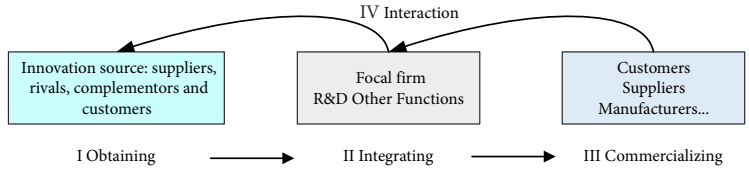

Figure 3. A four-phase process model for using external innovation sources

Scuotto et al. (2016) evaluated the OI model of IBM smart cities projects, which bridged the gap between the promotion of the Internet of Things and the pull of urban policy, to develop innovative and technological cities. Yang and Zhang (2017) selected three enterprises of the Hubei manufacturing industry and proposed that business model innovation was a booster for OI. Lee et al. (2017) explored the key activation factors of the Apple App Store based on the information and communications technologies intensive service innovations model. From an online OI community, Daradkeh (2021) presented that information timeless and completeness have a positive effect on the usefulness of user-generated content based on the bug comments collected from Huawei.

Accordingly, a suitable OI model plays a key role in the development of companies. With the rapid expansion of the research domain, there are different classifications for the OI model. Based on the results of a survey conducted by Accenture Purdue University on research and development of dozens of large companies in the United States and Europe, the OI model was summarized into four models[2]: (1) traditional intellectual property (IP) contract, that is, one of the two partners provides technologies, for example, by cooperating with top designers, H&M launched a series of products to achieve a brand differentiation (Zhu & Huang, 2012; Bican et al., 2017); (2) OI cooperation. When the project is complex or the company's project is difficult to advance, this model can be implemented. For example, to develop new technology, HP shared its server and cloud computing roadmap with DreamWorks Studios; (3) OI platform. Through the platform, enterprises can obtain the best solution from alternatives when they do not know where to get the innovation ideas (Adamczyk et al., 2011; Ojasalo & Tahtinen, 2016); (4) OI community. This model is more suitable for situations that the problem is more complicated and multilateral cooperation is required (Martinez-Torres, 2013). Also, the operating modes include university-industry collaboration (Bertello et al., 2021), enterprise technology alliance; technology mergers and acquisitions (M&A); technology purchase and outsourcing; technology transfer; develop internal technical achievements from external markets.

1.3. The risks and limits in practices

Under the circumstances of different OI models, there are some limits for enterprises (Bogers et al., 2019; Cheng & Huizingh, 2014; Burcharth et al., 2014; Huizingh, 2011; Lichtenthaler, 2008; Chesbrough, 2004). In general, the shortcomings of the OI model itself and the imperfections of internal and external environments of the enterprise will lead to the emergence of risks, specifically, brought by the uncertainty of capacity, technology, project, and market. For example, regarding the uncertainty of the capacity to collect innovation resources, Huawei has paid a high cost to establish cooperation with universities and research institutes. Thus, in order to implement integrated external and internal innovation resources and technologies well, enterprises need not only know their models but also clear how to select the suitable OI. The two factors, i.e., complexity and uncertainty, have persistent threats that cannot be underestimated in the development of OI (Bagherzadeh et al., 2021; Colombo et al., 2016). Then, Figure 4 presents the research framework of this paper.

[2] https://www.sohu.com/a/240894054_772814

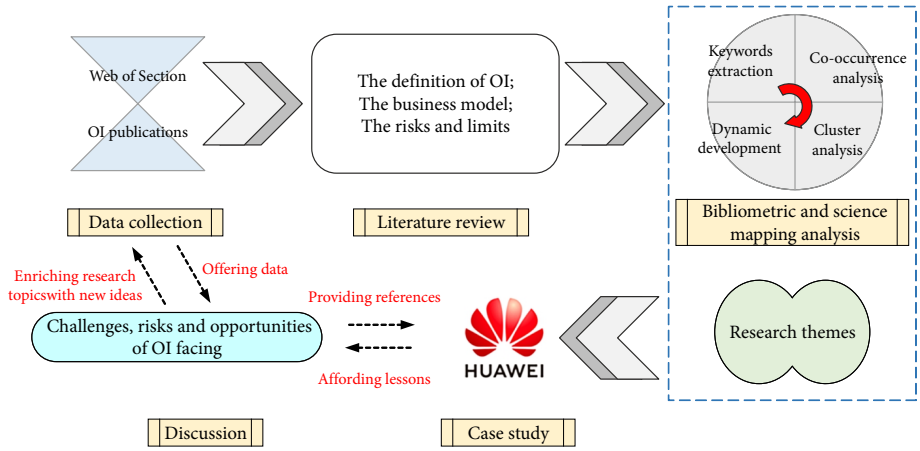

Figure 4. The research framework of this paper

2. Bibliometric and science mapping analysis

2.1. Research hotspots

To understand the transition, we divide the literature into 4 phases, i.e., 2003–2007, 2008–2012, 2013–2017, and 2018–2021. Based on SciMAT tools, we obtain the overlapping map of themes, as shown in Figure 5. There are 4 periods from left to right. The upward arrow indicates the number of keywords that have been eliminated, the downward arrow presents the number of new words, and the horizontal arrow explains the words maintained from the previous period to the next period. From. Figure 5, we can see that, in each period, the number of new words is greater than the number of keywords that have been eliminated. For example, from 2003 to 2007, there were 62 theme words, and then 241 new words were created and 42 were eliminated. The number of theme-words is increasing. The whole development trend of theme words reflects that the research content in the field of OI is getting abundant.

Sci2 is a new knowledge map analysis tool developed by Katy Börner and his team of Indiana University based on Cyber Infrastructure Shell (CIShell) (Zou et al., 2018). It provides operational services for data preparation, preprocessing, analysis, modeling, and visualization, which provides convenience for the content research in the field of OI. This paper extracts 4,496 publications from the Web of Science (WOS) with the topic "OI". The types of publications include articles, proceeding papers, book reviews, and review articles. After a series of data preprocessing, including removing duplicate records and merging records, 8,676 keywords are selected.

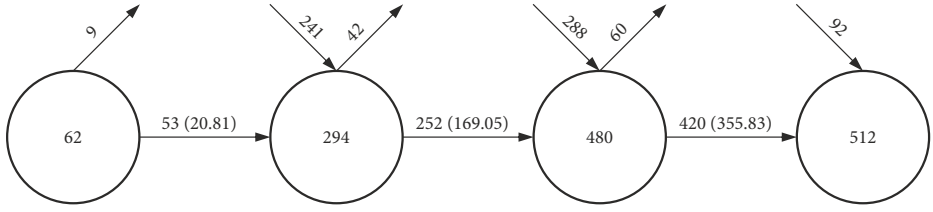

Figure 5. The overlapping map of themes

Then, the co-occurrences analysis and clustering are conducted. To reflect the core research hotspots, Figure 6a illustrates the co-occurrence networks based on the high-frequency keywords. The network consists of nodes and edges, representing the keywords and co-occurrence relationship, respectively. The size of the nodes represents the number of occurrences, and the square node is the most frequent keyword. The thicker the connection, the higher the co-occurrence of these two keywords. The top 20 high-frequency keywords include SMEs (123), absorptive capacity (116), knowledge management (104), co-creation (93), innovation management (89), new product development (68), case study (63), sustainability (56), technology transfer (55), R&D (51), etc. These keywords are classified into three clusters marked in different colors in Figure 6b. These high-frequency keywords and their connections initially indicate that the core research themes in this field are mainly focused on the development of SMEs.

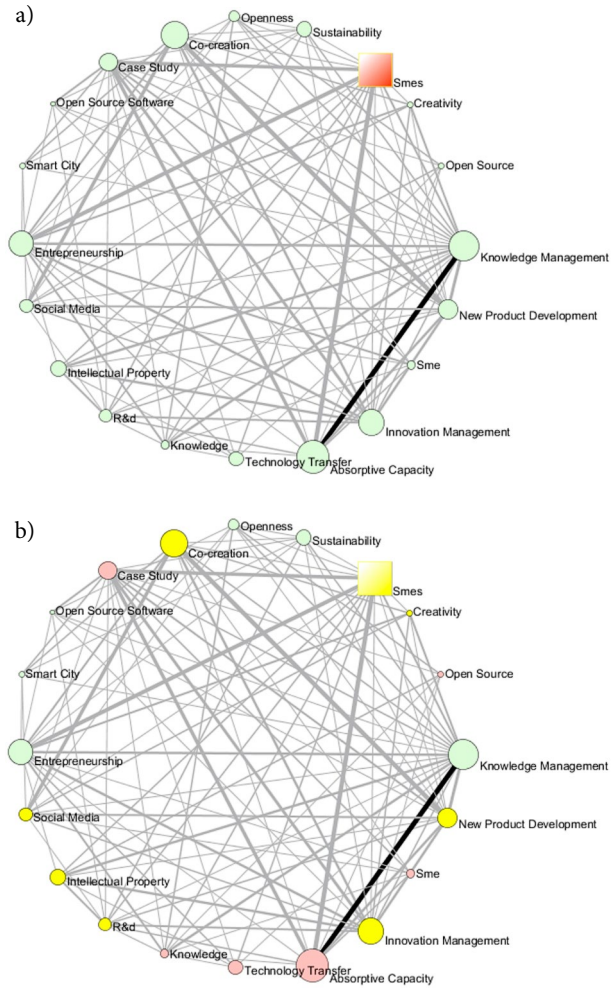

Figure 6. The co-occurrence network and clustering based on the top 20 high-frequency keywords: a – the co-occurrence network; b – Clustering results

2.2. Important research themes

Furthermore, to master the important research themes in the field of OI, the top 20 high-frequency keywords and their co-occurrence analysis are not sufficient. Thus, this subsection conducts the clustering with more core publications in this field. Initially, based on all keywords, the visualization results are shown in Figure 7a. There are 8,676 nodes. Next, by extracting the top 100 frequent keywords, the important research topics are classified into five clusters, as shown in Figure 7b. Combining with the corresponding publications, the five important research foci can be summarized as follows:

Cluster I. Resource management and value creation of SMEs.

(a) SMEs' OI: With multinational companies such as Procter & Gamble, Cisco, and Microsoft gradually accepting and benefiting from OI, scholars have gradually realized that OI also has great value for small and medium-sized enterprises. It attracts scholars to explore

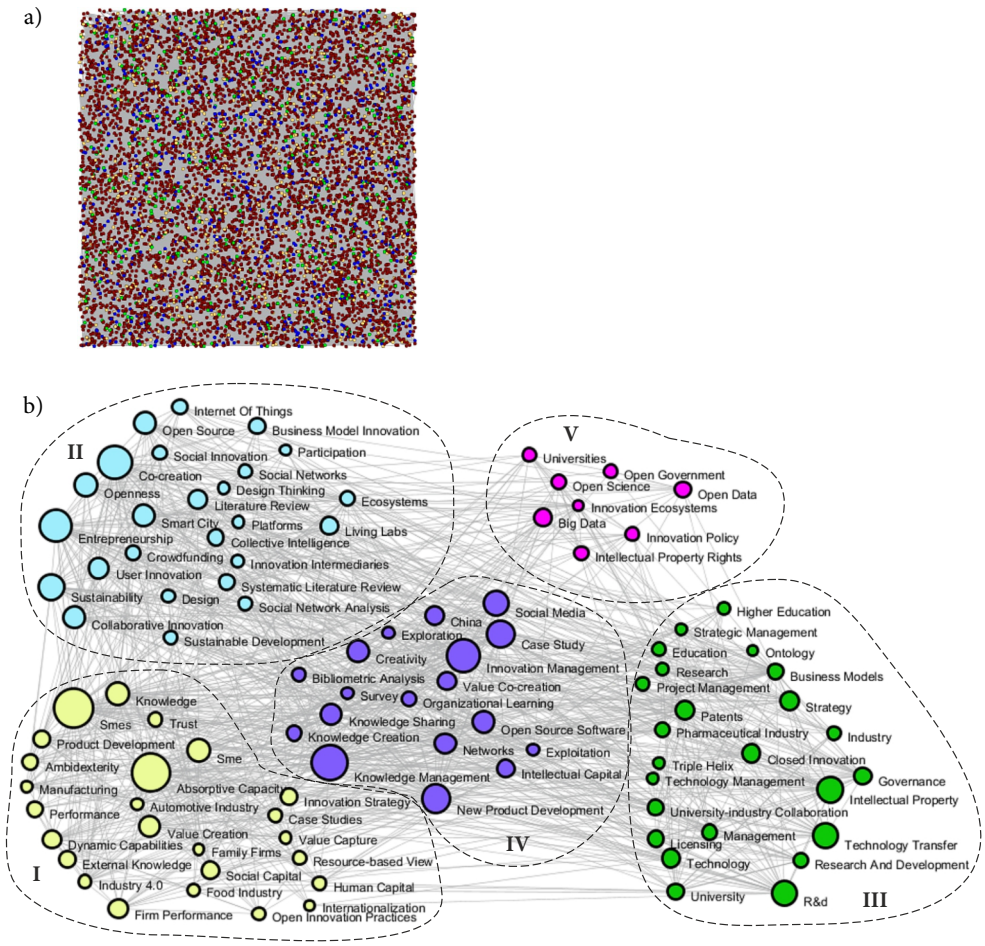

Figure 7. Keyword clustering results:
a – The cluster of all keywords; b – Clustering results based on Top 100 high-frequency keywords

the OI model of SMEs. SMEs will be more adaptable than large companies, benefiting from their small scale; (b) The dynamic integration of internal and external innovative resources: The effective integration is particularly important for the innovation and development of enterprises. In an open environment, efficient knowledge flow and cooperation networks (Djurian et al., 2021) are important factors that affect the integration of enterprise innovation resources and lay a solid foundation for research and development of core products; (c) The applications in different industries: To explore the characteristics of OI implemented by enterprises in different industries, scholars have launched a series of personalized studies. For example, Saguy and Sirotinskaya (2014) pointed that the food industry faces numerous complex challenges, especially SMEs in this industry. Some recommendations were proposed, including the creation of an innovation ecosystem consisting of industry, academia, government, and private business, and a new intellectual properties model, etc. By performing a survey with 130 automotive subsidiaries in Brazil, Gondim et al. (2017) found that a high distance of taxes increases the likelihood of the adoption of OI.

Cluster II. Collective innovation and form sustainability.

(a) To coordinate global technical cooperation resources, improve innovation efficiency, realize collective innovation and independent innovation, and apply external technologies, scholars have launched a series of studies; (b) Sustainable innovation is very important for enterprises to implement OI, and is one of the core content of enterprise innovation activities and gaining competitive advantages (Chesbrough & Appleyard, 2007; Chaston & Scott, 2012; Lopes et al., 2017; Rauter et al., 2019; Du et al., 2016; Behnam et al., 2018). After understanding the law of the OI model, how to choose a personalized business model that suits the enterprise, cultivate continuous innovation capabilities, eliminate institutional barriers, and gain competitive advantage is the goal of an enterprise to implement OI; (c) The construction of an OI platform and the new idea of smart cities are also the foci of this topic. The deep integration of the Internet of Things and urban development innovation from multiple perspectives of economy, ecology, technology, politics, and social culture are explained.

Cluster III. Innovation management, intellectual property management, and cross-border cooperation.

(a) A series of innovation management involving technology management, strategic management, and project management are valued in this theme module (Huizingh, 2011; Chiaroni et al., 2011; Porter & Newman, 2011; Guertler & Sick, 2021; Barbosa et al., 2021); (b) Patent is one of the main forms of protecting R&D achievements, and signing a payment agreement is an important form for enterprises to obtain open resources. In addition, IP transactions will also be involved in this process to realize the commercialization of research and development results (Zhu & Huang, 2012; Bican et al., 2017). Therefore, as an important intellectual property transaction model, IP outsourcing is a key research object for scholars and entrepreneurs (Symeonidou et al., 2017); (c) The cooperative objects in the process of OI mainly include universities, research institutes, enterprises, and governments. Therefore, the personalized innovation models for different partners are also worth exploring.

Cluster IV. Knowledge management and knowledge sharing.

(a) With economic and social progress, the operation and sustainable development of enterprises no longer depend on traditional resources such as nature and labor, but rather

intelligent resources such as technological innovation and professional knowledge. As companies continue to achieve cross-industry cooperation, knowledge management and sharing become particularly important. While ensuring that one's core technology is not stolen, it is one of the key contents of this topic to widely learn from external innovation ideas, choose new ideas suitable for the development, and realize knowledge sharing, knowledge creation and new product development; (b) Scholars introduced bibliometrics and the case study into this field (Yeung et al., 2021; Gao et al., 2020; Odriozola-Fernandez et al., 2019; Le et al., 2019). The former provides help for the comprehensive and systematic analysis of research content in related fields. For the individualized open business models of different companies, the case analysis helps scholars to quantify research problems, and at the same time provides entrepreneurs with theoretical reference and a decision-making basis.

Cluster V. Innovation ecosystem, big data, and policy-level innovation.

(a) The innovation ecosystem is an economic community with symbiotic relationships and an interconnected network based on long-term trust relationships (Siaw & Sarpong, 2021; Mei et al., 2019). It plays a key role in the development of OI. By emphasizing network collaboration between organizations, attaching importance to the mutual benefit and win-win of participants, and taking value creation and collaborative innovation as research topics, the innovation ecosystem has attracted wide attention from entrepreneurs and scholars in the field of OI. (b) With the rapid economic development, the openness of data is necessary. Therefore, the OI model in the big data environment is an effective way for current enterprise development (Del Vecchio et al., 2018). The future is the era of data and data contact. The collision of data between different industries inspires enterprise innovation models. For example, the meeting of telecommunications data and government data helps the construction of smart cities and helps cities plan places for people to live, work, and entertain; financial data and medical data can detect fraudulent insurance (Schaffers et al., 2011; Ferraris et al., 2020); (c) The support of relevant government policies provides a solid backing for the implementation of a series of innovative measures by enterprises. The formulation of the concepts, objectives, principles, subjects, and measures of related policies is another research focus of this topic.

2.3. Dynamic development trend and research frontiers

Next, this paper explores the dynamic development trend and research frontiers in the field of OI based on the burst detection function in CiteSpace. In the process, we select the top 20 levels and the top 10% of most-cited or occurred items from each slice, and then the top 22 keywords with the strongest citation bursts from 2003 to 2021. The results are presented in Table A1 (see Appendix). The earliest burst keywords are *intellectual property* (from 2007 to 2015) and *open source* (from 2007 to 2012). The former keyword has the longest duration of 9 years. *Sustainability* (from 2019 to 2021) has the strongest citation burst, i.e., 9.45. Besides, it also has an impact on this field, and it is expected to continue. According to the literature review in Section 1, we have presented the main three phases of OI development, establishing

sustainable advantages is in the third stage, which is the goal of enterprises to implement OI. The importance of this stage gradually emerged with the emergence of the keyword *sustainability*. It is constantly infiltrating into different fields, such as supply chain (Durmaz et al., 2021; Solaimani & Van der Veen, 2021), agri-food systems (Troise et al., 2021), and circular economy (Jesus & Jugend, 2023). Specifically, as the COVID-19 pandemic and more uncertain situations emerge, to process a sustainable supply chain framework (SSCF), Durmaz et al. (2021) studied a negative entropy and its role in the SSCF.

In addition, the keywords, i.e., *ecosystem* and *innovation performance*, still have an impact until the present. In general, in recent years, the research in the field of OI is currently focused on different stages of the strategic management of enterprises in different industries. In particular, the development of new products and OI platform, for example, the establishment of smart cities, have been gradually attracted attention. Cross-platform, cross-field, cross-disciplinary and personalized innovation models are also slowly emerging.

Furthermore, 1,906 documents published from 2018 to 2021 are extracted to investigate the research frontiers and possible emerging sub-fields in this field. By obtaining the top 20 and 50 high-frequency keywords, the co-occurrence and clustering networks are constructed, as shown in Figure 8. Three themes have been attracted more attention. These themes are: (1) The construction of the OI mechanism. It is related to fundamental research centered on how companies obtain open resources, build open platforms, and achieve cooperation between companies; the exploration of the role of an OI model in the operation of an enterprise; cultivating internal and external innovation capabilities of the enterprise, to lay the foundation for the formation of sustainable innovation; (2) Innovative resource management. Based on basic research, companies collect and select multi-source heterogeneous innovation resources and commercialization resources. with the help of science and technology such as big data, social media, and knowledge sharing, companies realize the joint management of internal and external knowledge and resources; (3) Cultivate innovation capabilities and form sustainable advantages. The innovative knowledge and theories in new fields and disciplines are continuously introduced to achieve personalized innovation models, such as university-industry collaboration. According to R&D systems, enterprises realize cross-industry cooperation and build cooperative innovation platforms. Combining the current development status of SMEs, based on case study methods, through the introduction of bibliometrics, the development characteristics of OI are explored comprehensively and systematically. In addition, the introduction of advanced technologies such as artificial intelligence enables the establishment of new architectures.

3. Case study-Huawei

Taking Huawei as the research object, this section studies the background, methods, effects, threats, development prospects, and opportunities of the implementation of OI. Also, this section explores its innovative ideas and reasons for quickly gaining a competitive advantage in the market, which is of references significance for the innovative development of SMEs.

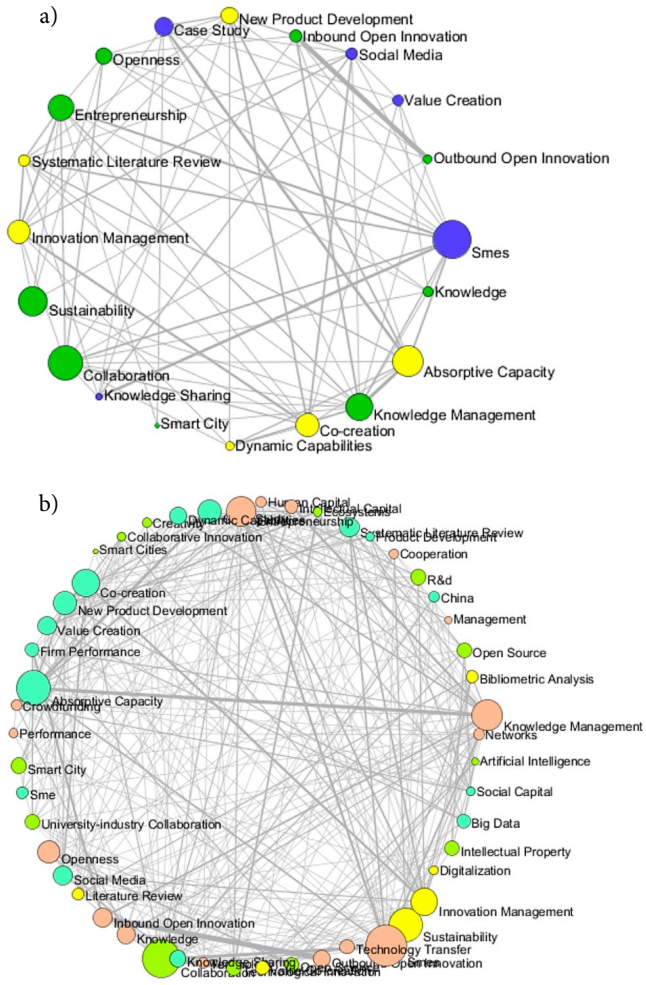

Figure 8. Clustering results based on the Top 20 and Top 50 high-frequency keywords published in 2018–2021

3.1. Background analysis

3.1.1. Reasons for Huawei's implementation of OI

Found in 1987, Huawei has gone through more than 30 years of struggle. At first, it mainly relied on agency methods to profit from the price difference. Due to the backward technology, it is unable to meet the market demand, resulting in the monopoly of imported equipment on the Chinese communication market and the situation of high prices (Wei, 2019).

Its goal is to establish a global company, communicate and cooperate with world-class companies. OI is a great opportunity for Huawei to develop industry and establish itself in the international market. The mainstream product of Huawei is communication equipment that is quickly updated. To keep up with the trend of times and the needs of customers, it must continue to develop advanced application technologies. At the same time, the coopera-

tion with the international high-end enterprises is necessary to guarantee that Huawei has access to obtaining external resources. With the consideration of immature communication technology, the obtained external innovative resource will help to reduce the costs of research and development and the risk of failure. Besides, the current innovation is mainly to transform the theoretical results decades ago into products needed by the market based on technological and engineering innovations. In the 5G era, coding has almost reached the limit of basic theories in the field of information and communication (Xu, 2019). As the leader of this field, Huawei has entered a "no man's land". To develop new technologies, it must continue to make breakthroughs. This indicates that Huawei's development of OI has encountered many bottlenecks.

3.1.2. Its OI approaches

Over the past 30 years, it is based on the innovation in the organization, technology, project, management, and consumer-based: (1) From the perspective of the organization, Huawei built a joint innovation department with international operations. At present, it has been established more than 16 R&D centers and 69 basic technology laboratories. The research contents were related to wireless and fixed broadband, cloud computing, communication terminals, materials, heat dissipation, mathematics, chips, and optical technology (Hu & Diao, 2021). Researchers working on the research and development of products account for nearly 50% of the total staff. More than half of the items in a project use advanced technologies from other countries. To promote the progress of digital transformation, Huawei also initiated the establishment of a cross-industry global organization. (2) Technically, to improve competitiveness, the development of core technologies has always been the focus of Huawei. It is worth mentioning that as early as 1991, Huawei designed the first ASIC chip and established a chip design office. Now, its product "Kirin 990" is the world's most advanced 5G mobile phone chip. (3) From the project-related aspect, Huawei cooperates with universities, research institutes, and business giants. Through cooperation, research and development, the research results are transformed into products to achieve commercialization. For example, in the fields of chip, artificial intelligence and computer science, Huawei has carried out 286 collaborations with 34 scientific research teams of the Chinese Academy of Sciences. Moreover, it has reached cooperation with business giants including IBM, Siemens, Panasonic, Intel, and so on. The cooperation with IBM mainly involves four aspects: R&D management reform, supply chain management reform, financial management reform, and strategic management reform. The TD-SCDMA technology patent owned by Siemens has attracted the attention of Huawei. By signing an agreement, Huawei uses this technology to make up for its shortcomings in WCDMA. At the same time, Siemens has a good customer relationship network in Europe, which helps Huawei achieve breakthroughs in sales of data communication products in Europe. Similarly, the cooperation between Huawei and Panasonic can not only improve the technical content of mobile phone terminals but also help bring a series of products into the Japanese market. (4) From the management aspect, it has hired outstanding foreign consulting and management experts, resulting in a substantial increase in the number of patents granted annually. (5) From the perspective of consumers: it emphasizes "customer-centric" innovation, established a three-level IT-supported demand

management process and decision-making system, and extended it to the market terminals. It created a system that integrates 2G, 3G, 4G, and 5G, which not only helps to reduce operating cost and increase the speed of network construction[3]. At present, the series of products have huge technical and commercial advantages, so that European manufacturers have to follow Huawei and launch similar products. These products have become industry standards and lead the development direction of the wireless industry.

3.1.3. The effects of its OI approaches

As a latecomer, Huawei's OI approaches have enabled it to transform from catching up to leading the way. OI has brought it breakthroughs. Next, we analyze its effects from two aspects: financial performance and innovation performance.

Financial indicators can reflect the operating conditions, and financial performance well highlights the results brought to Huawei by its OI approaches. This paper conducts the analysis from the perspective of profitability and growth capacity, using data from the annual report (2005–2020) published on Huawei's official website. In respect of profitability, the operating profit rate and net profit rate are shown in Figure 9. From Figure 9, we found that Huawei's operating profit rate and net profit rate both reached their peak in 2010 in the past 16 years. From 2005 to 2010, the operating profit rates is about 13% and net profit rates is about 10%. After 2010, it maintained an operating profit rate of about 10% and a net profit rate of about 7%. The main reason for the sharp drop-in profit rates in 2011 was that Huawei increased its investment in R&D. The behavior ensured that it maintained a strong competitiveness in an increasingly competitive international environment, and the high profit rate under the conditions of the industry average dropped or even fell to a negative value. In addition, it also weakened the economic downturn caused by the COVID-19. These are the long-term benefits brought by the OI mechanism to Huawei. Regarding Huawei's growth capabilities, it is mainly analyzed from the indicators of sales revenue and net profit as shown in Figure 10 and Figure 11.

From Figure 10, the sales revenue is on the rise, with a considerable growth rate, mostly above 15%, and even more than 30% in some years. Figure 11 shows that the growth rate of net profit is higher than the growth rate of sales revenue most of the time. Within a few years, abnormalities have occurred due to the external environment and increased internal R&D investment (Qin, 2020). Overall, Huawei has shown the positive growth capability, which is closely related to its long-term OI approaches.

In terms of innovation performance, many scholars have proposed different measurement methods, and the measurement dimensions have gradually increased. Innovation performance can be calculated through six five-point items (Liu et al., 2016), but the amount of calculation is large and the assignment is subjective. In this paper, the number of patents is used to measure innovation performance, specifically the cumulative number of valid authorized patents. The results are shown in Figure 12. In the past decade year, Huawei has always insisted on investing more than 10% of its sales revenue in R&D, even more than 15%. These approaches have enabled Huawei to explode in the number of effective authorized patents, and it has leapt to the forefront of the world.

[3] https://zhuanlan.zhihu.com/p/379719673

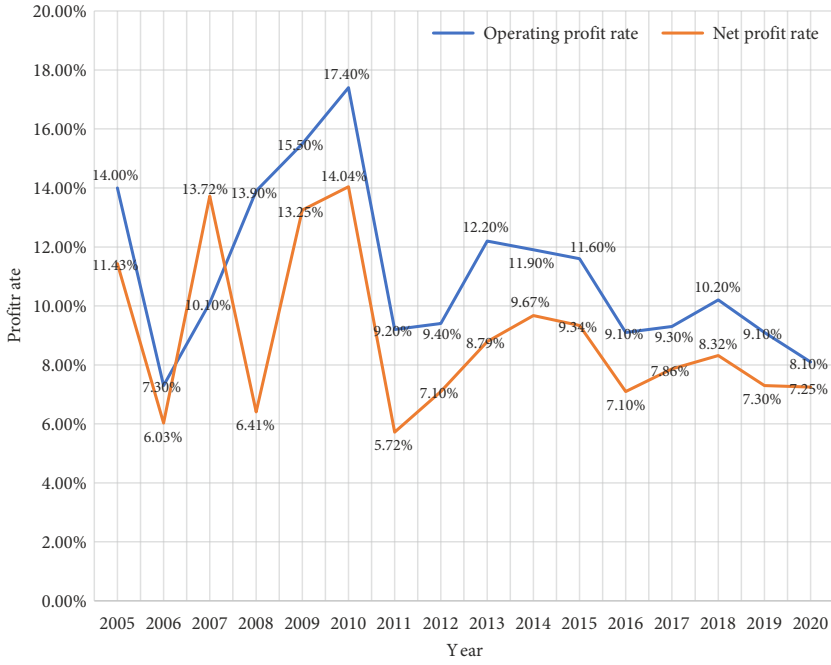

Figure 9. Profitability in 2005–2020

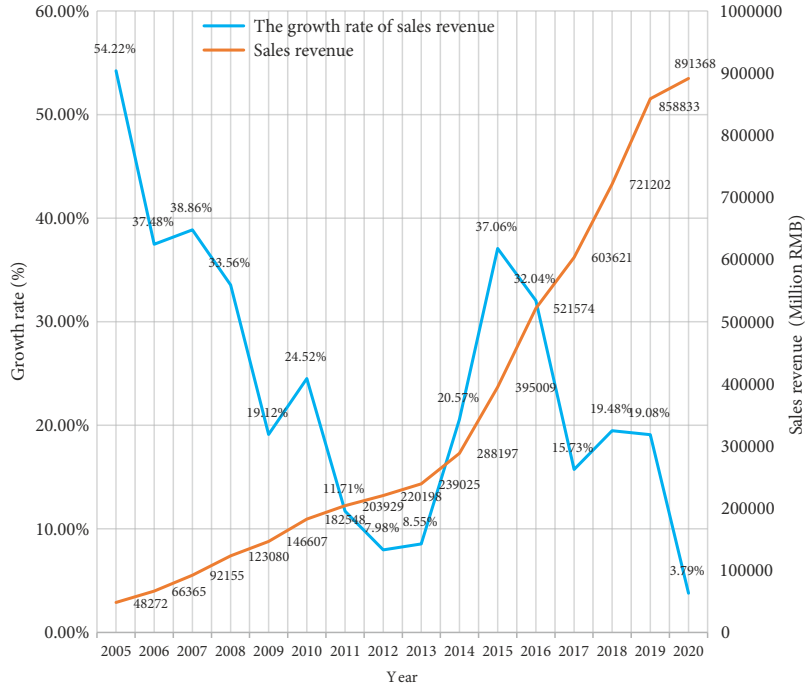

Figure 10. The growth rate of revenue in 2005–2020

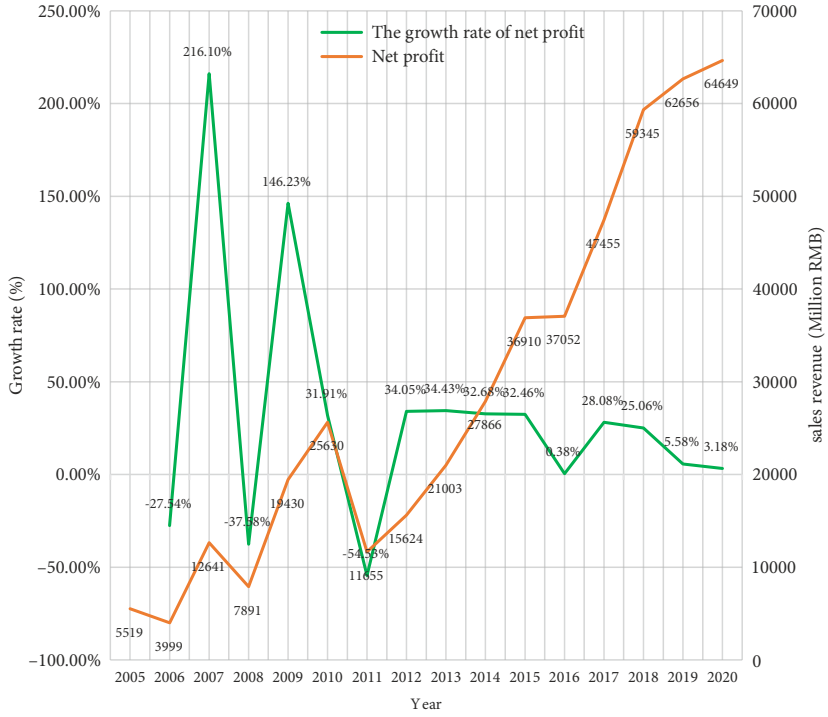

Figure 11. The growth rate of net profit in 2005–2020

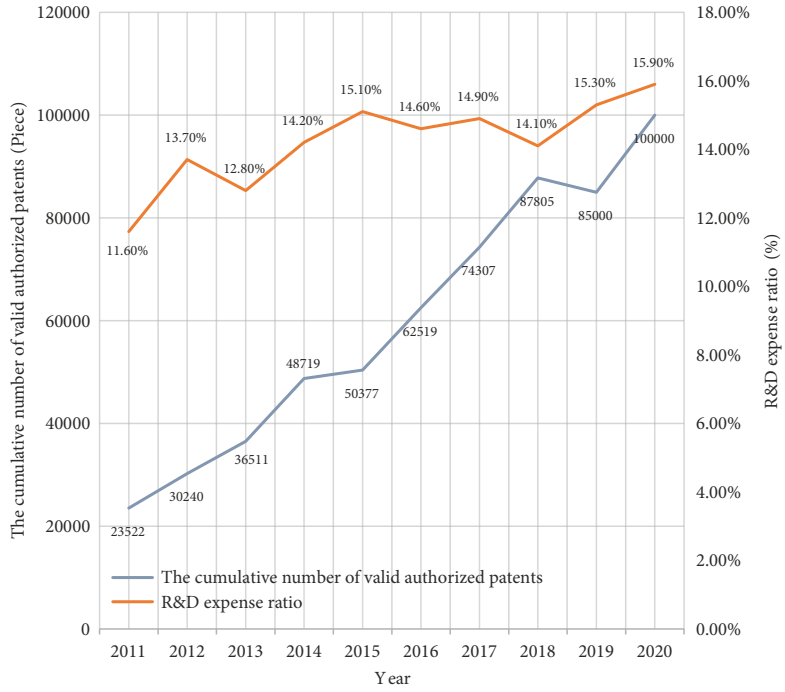

Figure 12. The cumulative number of valid authorized patents and R&D expense ratio in 2010–2020

3.2. Threats and development prospects

With the widespread popularity of OI, more domestic and foreign companies are rising. As a communication manufacturing company, Huawei has the following main competitors: Nokia, Ericsson, ZTE, BICT, and Cisco. As far as mobile phone terminal manufacturers are concerned, in the international market, Apple and Samsung pose a threat to Huawei. In addition, OPPO and Xiaomi can compete with Huawei in China. Enterprise applications also belong to the main business scope of Huawei. The existence of many competitors puts pressure on the development of Huawei's OI model. On the other hand, due to excessive acquisition of companies, payment of fees to sign patent agreements, and OEM production, once a mandatory policy emerges, it will have an adverse impact on Huawei.

The evolution of Huawei's OI has mainly gone through three stages, namely imitative innovation, independent innovation supplemented by cooperation, and overall innovation, collective innovation, and independent innovation. With the advancement of science and technology, as the human society may evolve into an intelligent society, Huawei has a large room for development in the next stage. Based on applications of various advanced technologies and ICT infrastructures, such as cloud computing, big data, 5G, Internet of Things, and artificial intelligence, it is expected to connect all data online. Facing the smart society in the future, it needs to break the theoretical and basic technical bottlenecks that restrict the development of ICT and realize theoretical breakthroughs and innovations in technological inventions. Furthermore, it is necessary to realize a strong alliance between universities, research institutions, academia, and industry aimed to use global scientific research resources and talents for cooperative innovation. Besides, while strengthening basic research and promoting scientific progress, it actively adopts various methods, such as establishing laboratories and investing in multi-path technology. Integrating the problems of industry, the ideas of academia, and the beliefs of venture capital will help promote the realization of joint innovation.

4. Further discussion

OI is the main form of enterprise innovation in the era of a knowledge economy, and it is also the core idea of economic development in China. However, an OI framework that adapts to the national conditions has not yet been formed, and its innovation process still needs to be studied. Nowadays, China's innovation system is still in an imperfect state. There is a lack of an ecological environment conducive to OI.

Specifically, from the government level, the construction of conceptual resources needs to be further strengthened. For example, the Chinese government should also take some countermeasures, for the issue of US restrictions on chip manufacturers to sell chips to Huawei. From the perspective of the innovation subjects and individuals, there is an urgent need to establish an awareness of innovation and strengthen the cultivation of innovation capabilities, which is conducive to responding to an OI system. From the project-related environment, innovation projects generally have two characteristics, that is complexity and uncertainty. For example, project partners are usually composed of scholars, technical developers, and managers with different work experience and disciplinary backgrounds from different fields.

The different levels of cognition and professionalism bring a large degree of uncertainty to the project decision-making process.

In addition, the economy in China is in a stage of rapid development, SMEs have an important position and role. They are the important supporting force to promote the sustained, rapid and healthy development of the national economy. Thus, it is inevitable to promote, apply and effectively implement OI in SMEs. As the foundation of OI, the development of enterprise technological innovation capabilities plays a vital role. However, most domestic SMEs currently mainly adopt imitation and imitative innovation methods and lack the awareness and ability to cooperate and independent innovation. Also, there are problems such as relatively lagging management concepts and a lack of marketing methods. Therefore, they still face many problems and difficulties. In addition, with the consideration of shortage of funds, lack of talents, and poor ability to resist risks, how they accurately select the objects of imitation innovation and determine the ways to imitate innovation are also the questions worth pondering. For the collaborative innovation, SMEs may have their intellectual property stolen by the other company, and lose their competitive advantage, which is a major obstacle for SMEs to carry out OI.

Combining the implement of Huawei's OI model and the challenges faced by SMEs, there are several references to SMEs in China: (1) actively paying patent fees, attaching great importance to technological innovation, increasing investment in innovation resources, mastering core technology, and striving to shorten the path from imitating innovation to independent innovation; (2) achieving theoretical innovation and technological innovation "racing together bridle to bridle", and paying more attention to the product development process; (3) integrating external innovation resources across organizational boundaries to achiever cross-border cooperation; (4) strengthening cooperation with enterprises, universities and research institutes; (5) making full use of talent resources; (6) strengthening the entrepreneurs quality and increasing the willingness of independent innovation; (7) improving risk management capabilities, strengthening the construction of internal innovation systems within the organization; (8) enhancing the ability to interact with resources and deal with many risks under the fuzzy and uncertain environments.

In addition, this paper proposes the possible development opportunities. Firstly, considering the complexity and uncertainty of innovation processes, the introduction and in-depth research of a series of fuzzy decision-making methods are necessary and very helpful to the implementation process of OI, such as the improvement of risk identification capabilities. Then, as one of the underlying technologies of the next-generation Internet, the application of blockchain technology has brought major innovation opportunities, such as business model innovation, and the formation of an ecological business model, which is used to solve things that require multi-party participation and large-scale collaboration in SMEs. There is an urgent need to reconnect, match and reconstruct the relevant knowledge and experience within the organization and the innovation resources. Furthermore, with the digitalization of cities and the deep development of intelligence, urban wisdom has been widely promoted worldwide. To realize the coordinated management of urban physical and digital worlds, a unified operating system is necessary. Based on AI capabilities, the different data, systems,

and applications of cities need to be continuously integrated to realize the analysis and decision -making of various events and improve the efficiency of urban resource scheduling. Thus, the operation and development of the AI platform is always prioritized.

Conclusions

This paper first briefly reviews the concept, business models, limits, and risks of OI. This part helps us have a preliminary understanding of the current development trends of OI and lay a solid foundation for the research hotspots and research dynamic development. In addition, it also provides the analysis directions for the case study in this paper. Furthermore, by introducing bibliometrics and science mapping analysis, the co-occurrence analysis, clustering, and burst detection analysis are also applied to explore the research hotspots and important research themes based on the high frequent keywords. It is found that, the current researches in this field mainly focus on the product development, knowledge management, and innovation resource acquisition, especially for the SMEs. In the future, we can deduce that, the advantage of forming sustainable development will become the key research topic, while exploring the existing research in depth. As a typical enterprise, the backgrounds, and approaches of Huawei to implement OI are introduced. Combining with China's national conditions, the prediction of Huawei's innovation model provides an important reference for Chinese SMEs to follow and improve their technological innovation capabilities.

Considering the limits of OI in Chinese enterprises, especially for SMEs, this paper initially explores the current challenges and opportunities. With the continuous development of the economy and society in China, as well as the breakthroughs in related theoretical methods and technologies, OI has broad room for progress. In the future, we will continue to pay attention to its compatibility under China's national conditions and enrich our understanding of OI.

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APPENDIX

Table A1. The keywords with the strongest citations bursts from 2003–2021

Keywords	Year	Strength	Begin	End	2003–2021
intellectual property	2003	8.94	2007	2015	
open source	2003	3.89	2007	2012	
technology transfer	2003	4.47	2008	2013	
open source software	2003	7.14	2009	2014	
closed innovation	2003	3.45	2009	2015	
online community	2003	3.11	2009	2012	
service innovation	2003	4.16	2012	2014	
r&d	2003	9.01	2013	2015	
creativity	2003	6.71	2013	2015	
patent	2003	5.08	2013	2017	
living lab	2003	4.38	2013	2014	
social media	2003	5.88	2014	2016	
strategy	2003	5.02	2014	2016	
university	2003	3.87	2015	2016	
smart city	2003	11	2016	2018	
innovation management	2003	5.39	2016	2019	
new product development	2003	4.16	2016	2017	
network	2003	3.53	2016	2018	
knowledge	2003	6.99	2018	2019	
sustainability	2003	9.45	2019	2021	
ecosystem	2003	6.97	2019	2021	
innovation performance	2003	4.54	2019	2021	