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Evolution of Innovation Ecosystem and Policy for an Emerging Industry: A Case of Additive Manufacturing Industry

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Abstract: Constructing and improving an innovation ecosystem for emerging industries is vital for success in the scientific and technological revolution and industrial transformation era. In this paper, additive manufacturing industry is presented as an example. The development stages of an innovation ecosystem is introduced, and the characteristics in terms of science, technology, market, and policy as well as their co-evolution are analyzed using multisource heterogeneous data such as literature, patents, and commerce. Research shows that, with the implementation of innovation policies, the scientific output and technical level of the additive manufacturing industry improved gradually, and the market size of the industry expanded. However, the industrial chain of the additive manufacturing industry is unbalanced in development, the impetus for the transformation of scientific and technological achievements is inadequate, and the commercialization level of these achievements is low. Furthermore, to develop an innovation ecosystem for emerging industries, some policy suggestions are proposed; these include improving the capability of independent innovation in key links of the industrial chain to achieve independent and controllable industrial development, accelerating the industrialization of scientific and technological achievements, strengthening science and technology intermediary services, improving the transforming mechanism of scientific and technological achievements, and investigating new application areas, by integrating emerging industries with traditional industries, thereby achieving leapfrog development.

Keywords: emerging industry; innovation ecosystem; innovation policy; additive manufacturing; evolution

1 Introduction

Cultivating and developing strategic emerging industries is vital for technological and economic development. The *National Development Plan for Strategic Emerging Industries During the 13th Five-Year Plan Period* indicates that strategic emerging industries, such as the new generation of information technology, high-end equipment manufacturing, new materials, biology, new energy vehicles, new energy, energy conservation, and environmental protection, exhibit typical features of intensive knowledge technologies, promising development potentials, and comprehensive benefits. They are the core impetus for economic development and enable international competitive advantages in the future. Currently, emerging industries are still in the growth stage, which not only depends on its own progress in science and technology but also relates to relevant supporting technologies, complementary products, and macro-environments. Therefore, the development of emerging

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industries requires the establishment of innovation ecosystems to promote synergies among diversified entities in the system.

To achieve innovation breakthroughs in emerging industries, the support of industrial environments and the coordination of participants are necessary [1]. Disregarding the development of relevant supporting technologies and complementary products might result in failure [2]. The industrial innovation ecosystem is an organic system composed of universities, scientific research institutions, material suppliers, core producers, intermediary organizations, consumers, and other industrial participants [3], which promotes the healthy and sustainable development of the industry. Specifically, the innovation ecosystem includes both knowledge and business ecosystems [4]. Scientific and technical knowledge generated in the knowledge ecosystem [5,6] must be utilized in the market to realize its commercial value. However, existing research regarding innovation ecosystems in emerging industries mainly focuses on a single perspective, which does not emphasize adequately on the interactions among science, technology, and the market in the innovation ecosystem [7,8]. In addition, theoretical research combined with the specific context of China must be analyzed [9]. The interactions among science, technology, and business in the innovation ecosystem in China are worthy of further investigation.

Because capital and talent shortages, fast development of technologies, insufficient industrial support, and high uncertainties are often encountered in emerging industries at the early stage, it is difficult to achieve sustainable development in emerging industries based on only market mechanisms. It is therefore important to comprehensively use various policy tools to guide and support the construction of industrial innovation ecosystems. Typical policy tools can be classified into three types: supply-side, environmental, and demand-side policies [10]. Effective innovative policies can guide, stimulate, serve, and regulate the development of industry [11]; hence, they are important complements to market mechanism.

The aim of this study is to analyze an innovation ecosystem that comprises three subsystems, i.e., the science, technology, and business ecosystems, and investigate the interaction and synergy between the emerging industrial policy and these three subsystems. The remainder of this paper is organized as follows. First, the research design and data methodology are described. Next, using the additive manufacturing industry as an example, the three sub-systems are analyzed at different stages of industrial development. Subsequently, the co-evolution of the policy and innovation ecosystem is analyzed. Finally, some policy suggestions are proposed to promote the development of innovation ecosystems in emerging industries.

2 Methodology

2.1 Research framework

The innovation ecosystem can be classified into the science, technology, and business ecosystems. Based on this, the framework of a multilayer innovation ecosystem can be constructed for an emerging industry, involving interactions among science, technology, and business (Fig. 1). The science ecosystem focuses on basic research and the generation of scientific knowledge, providing scientific motivation for the sustainable development of innovation ecosystems. The technology ecosystem emphasizes technological research and development (R&D) and the generation of application technological knowledge, thereby providing technological support for the development of innovation ecosystems. The business ecosystem focuses on product development and the realization of commercial value, thereby providing a market pull for value creation and capture in the innovation ecosystem. In this framework, the government, as an exogenous force of the innovation ecosystem, affects each subsystem through various policy tools. Furthermore, this study investigates the interaction between emerging industrial policy and the three sub-systems in the innovation ecosystem.

2.2 Industry selection

The additive manufacturing industry (three-dimensional (3D) printing industry) was selected as a representative emerging industry in this study for the following reasons. First, additive manufacturing is regarded as a national key development direction of science and technology and it relates to high-end equipment manufacturing and the new materials industry. Furthermore, this industry exhibits the typical characteristics of emerging industry development and can therefore significantly improve the national manufacturing level and enhance international competitiveness.

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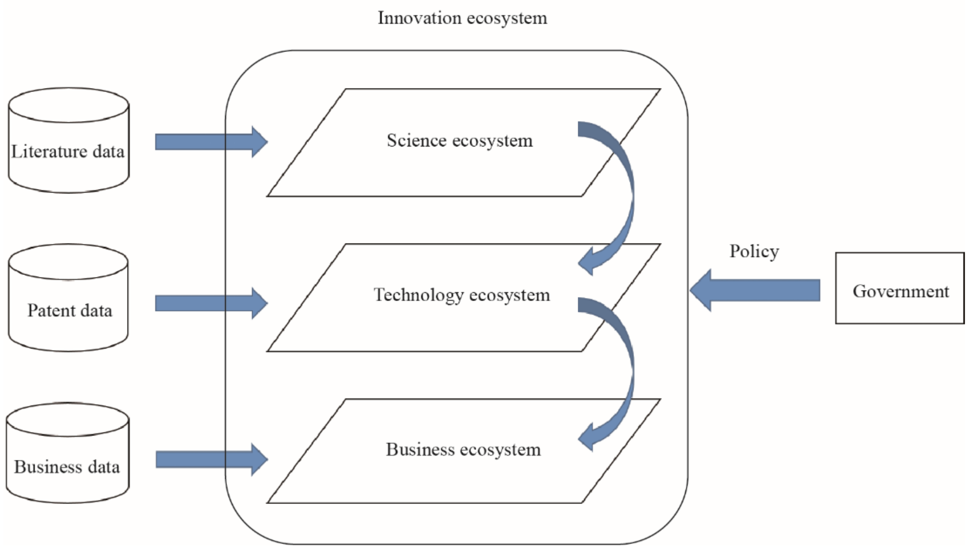

Fig. 1. Three-layer frame of innovation ecosystem.

2.3 Data source

Data were gathered from the following sources: (1) Literature data were collected from the core collection database of Web of Science. A total of 63 779 literature data points were acquired from 2005 to 2019.① (2) Patent data were collected from the Derwent World Patent Index (DWPI). A total of 46 676 patent data were acquired from 2005 to 2019.② (3) Business data were collected from news, industrial reports, firms' annual reports, and expert interviews. The retrieval deadline of the data above was September 21, 2019.

2.4 Methodology

2.4.1 Research methods

First, the evolution of the industrial innovation ecosystem was classified into three stages according to the additive manufacturing industry output value trend over the years. Next, based on the literature, patent, and business data, the development level and change trend of the additive manufacturing industry in the science, technology, and business ecosystems in the three stages were analyzed. Subsequently, additive manufacturing industrial policies were collected and classified to identify the distribution of policy tools. Finally, the co-evolution of industrial innovation policies and innovation ecosystems in additive manufacturing was investigated.

2.4.2 Research tools

(1) Derwent data analyzer: A data metrological analysis tool developed by Thomson Reuters. It was applied to data cleaning, deep mining, and matrix generation.

(2) Ucinet software: It can visualize the matrix. The global and China's scientific and patent collaboration networks were constructed using the literature and patent collaboration matrix to investigate the evolution trend of the additive manufacturing industry.

3 Evolution of innovation ecosystem of additive manufacturing industry

3.1 Industry background

Additive manufacturing is an emerging manufacturing technology that stacks materials to physical objects layer by layer. This may shift the manufacturing paradigm from equal material manufacturing and reductive material

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①In this study, literature retrieval form was determined "(3*D printing) OR (three-dimensional printing) OR (3-dimensional printing) OR (material increase manufact*) OR (additive* manufact*) OR (rapid* prototyp*) OR (rapid manufact*) OR (rapid* prototyp* manufact*) OR (Layered Manufact* Technology) OR (Solid free-form Fabrication) OR (Stereo Lithography Apparatus) OR (Laminated Object Manufact*) OR (Selective Laser Sinter*) OR (Fused Deposition Model*) OR (Laser Engineered Net Shap*) OR (Patternless Casting Manufact*) OR (Direct Metal Laser-Sinter*) OR (Direct Laser Fabrication) OR (direct metal deposition) OR (Laser clad* forming technology) OR (Electron Beam Selective Melt*) OR (Digital bricklay*) OR (3D mosaic) OR (ballistic particle manufact*)"

② Patent retrieval forms are same with those of literature retrieval.

manufacturing to additive manufacturing. The additive manufacturing industry can be classified into four value chain segments: material, design, preparation, and application [7]. The continuous integration of different value chain segments enables the sustainable development of the additive manufacturing industry. As a high-potential emerging industry, additive manufacturing has resulted in significant changes to the development of manufacturing technology, causing a shift in the manufacturing paradigm. Countries worldwide have launched a new phase of technology deployment and implemented development plans and measures for additive manufacturing, such as the *Action Plan for the Development of Additive Manufacturing Industry (2017–2020)* released by China, *Leading Strategy for Advanced Manufacturing* released by the United States, *European Additive Manufacturing Strategy* released by the the European Union, *Revitalization Plan for Additive Manufacturing Industry (2017–2019)* released by South Korea, and *Overview of Additive Manufacturing Research and Innovation* released by the United Kingdom.

The global additive manufacturing industry output value continued to increase during the period 2005–2018 (Fig. 2) and can be classified into three stages: the first stage from 2005 to 2009 is the introduction stage of the industry, in which the output value of the industry increased slowly. The second stage from 2010 to 2014 is the growth stage, in which the annual output value increased rapidly with an average increasing rate of approximately 30%. The third stage from 2015 to 2019 is the sustained-growth stage. Although the growth rate declined to a certain extent, the overall output value increased continuously. In the following sections, the additive manufacturing industry will be analyzed in three stages: 2005–2009, 2010–2014, and 2015–2019.

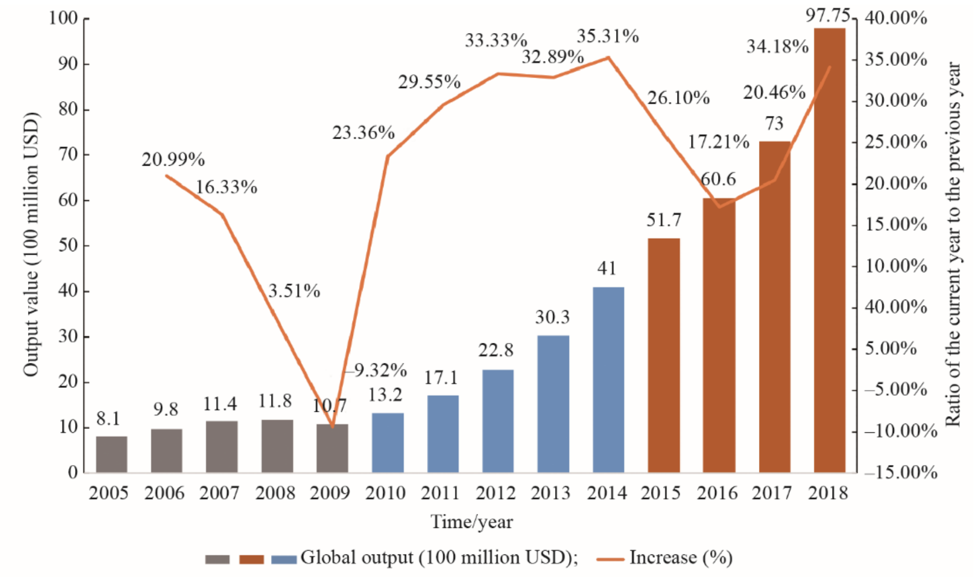

Fig. 2. Global additive manufacturing industry output value and growth rate from 2005–2018.
Source: Wohlers Associates.

3.2 Science ecosystem

The science ecosystem development of the additive manufacturing industry retrieved from the Web of Science database is illustrated. The number of studies published at the three stages were 9643, 15 349, and 38 787, respectively. In terms of the number of publications in the global additive manufacturing industry from 2005 to 2019, the United States and China were the world leaders (Fig. 3). The United States published 17 630 articles, constituting 27.71% of the total. China ranked second with 12 800, constituting 20.12% of the total. From 2005 to 2019, the amount of literature published in the United States and China increased annually (Fig. 4).

Scientific collaboration in the additive manufacturing industry at the three stages was analyzed from the following two aspects.

3.2.1. Global scientific collaboration network of top 100 entities

From the perspective of global scientific output, two, five, and seven Chinese entities existed in the top 10 at the corresponding three stages. This shows that China's research institutions constitute an ever-increasing proportion of the world's leading institutions, and that it has a prominent advantage in the accumulation of basic scientific knowledge in the field of additive manufacturing.

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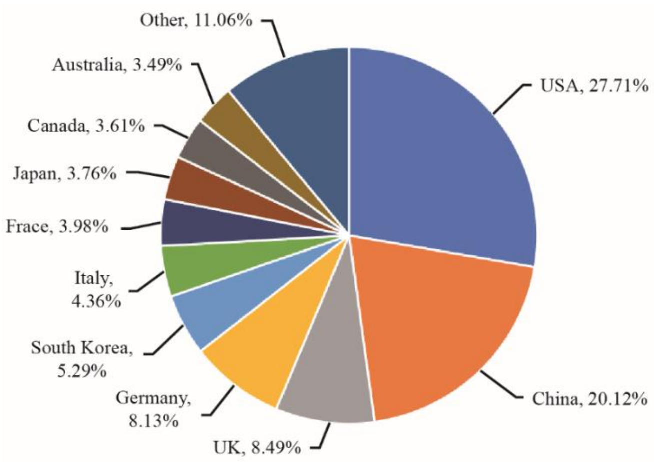

Fig. 3. Distribution of literature related to additive manufacturing during period 2005–2019.

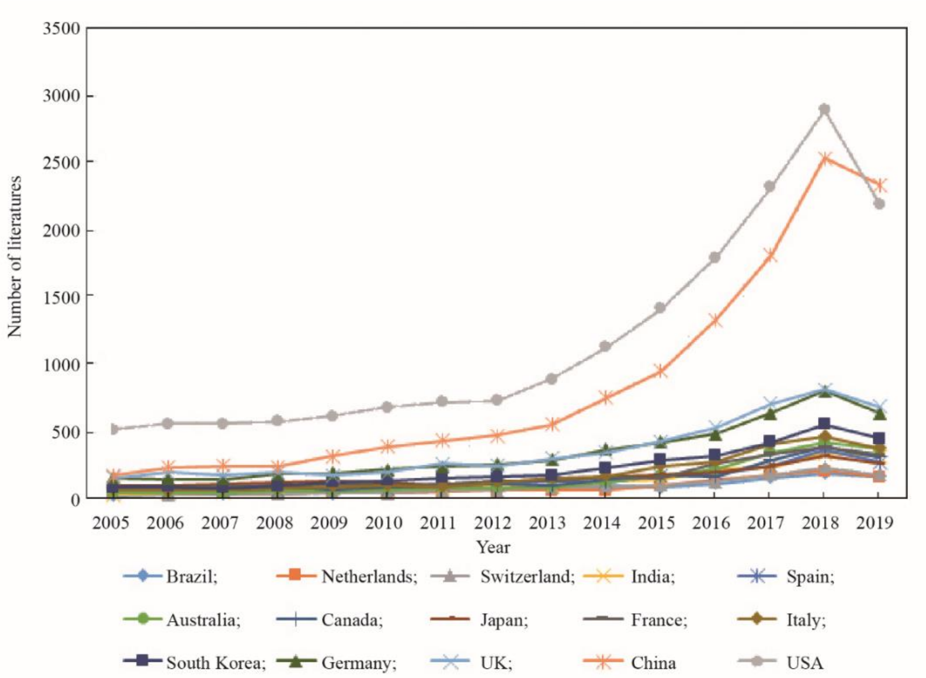

Fig. 4. Number of literatures related to additive manufacturing during period 2005–2019.

Notes: A lag phase of 6 months to 1 year from publishing to retrieval data applied in this study. The retrieval deadline of data was September 21st, 2019.

From the perspective of the global scientific collaboration network structure, the United States assumes an important position, and China has a strong momentum to be on par with the United States. In the first phase, i.e., from 2005 to 2009, most scientific collaborations were between US research institutions in the global scientific collaboration network. China gradually moved to the center of the network in the next two phases. Particularly in the third phase from 2015 to 2019, China was almost as productive as the United States (Fig. 5). This also indicates that China was accelerating the pace of basic knowledge investigation, and domestic research institutions were becoming increasingly active in terms of international collaboration. Domestic research institutions can absorb foreign frontier scientific and technological knowledge. Furthermore, they can collaborate with the international community to share resources and platforms. In addition, with the significant increase in the number of publications in China and the United States, countries worldwide have cooperated closely with those two countries. In terms of the scientific collaboration network, the density of networks has gradually increased at the three stages.

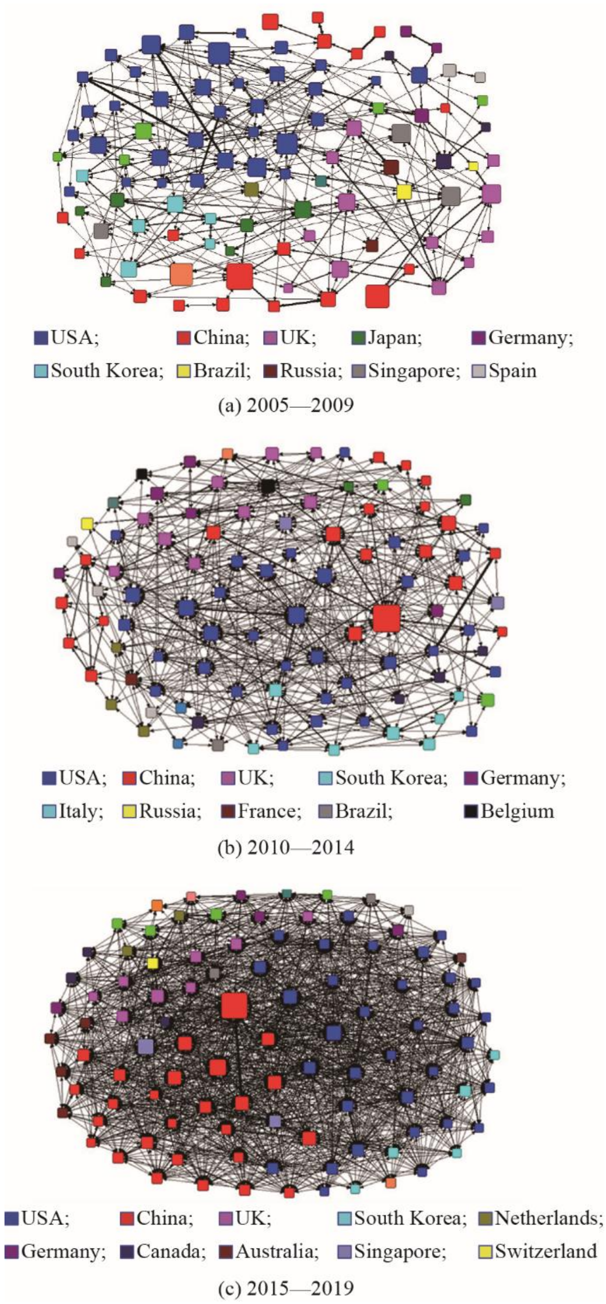

Fig. 5. Global scientific collaboration network of top 100 entities.

Notes: Boxes in different colors represent entities from different countries. For example, the blue box represents entities from the United States, and the red box represents institutes from China. The area of the box reflects the amount of literature published by the entity.

3.2.2 China's scientific collaboration network of top 50 entities

The members of China's scientific collaboration network of top 50 entities were all universities and research institutes, with no enterprises participating in it (Fig. 6); this implies that the creation of scientific knowledge in China was primarily from universities and research institutes. In general, the network graphs of the three stages became denser and more aggregated, indicating that the collaboration level of various institutions was constantly improving in the additive manufacturing field of China.

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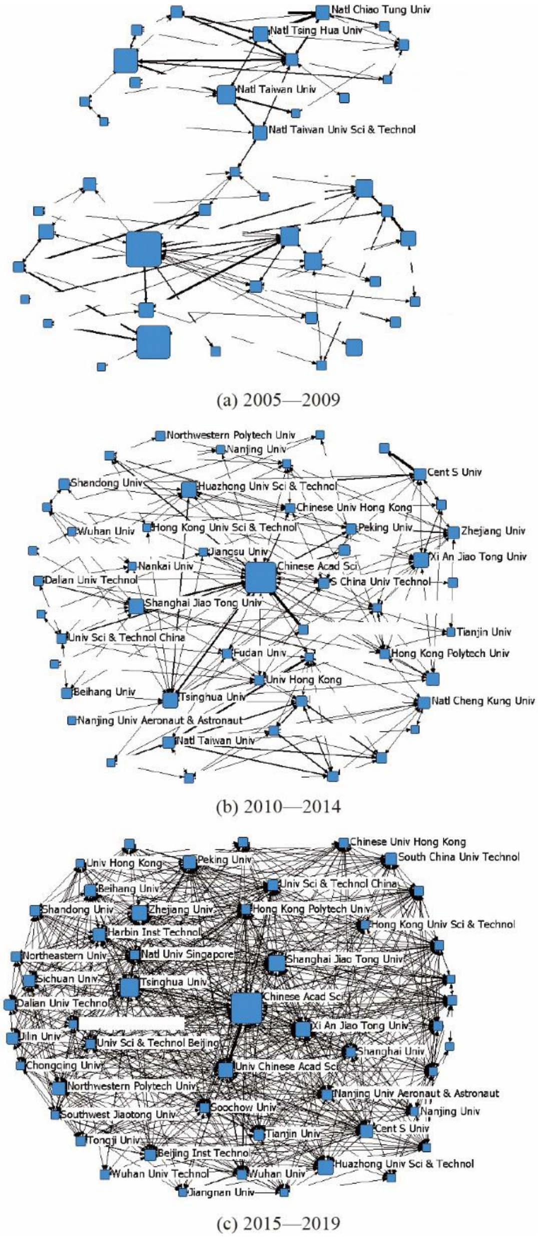

Fig. 6. China's scientific collaboration network of top 50 entities.

3.3 Technology ecosystem

The development of the technology ecosystem in the global additive manufacturing industry is illustrated by the patents retrieved from the DWPI. The numbers of patents applied at the three stages were 1508, 4667, and 40 501, correspondingly. Patent analysis was performed to analyze the distribution and trend of patent applications in various countries as well as the global collaboration networks and China's local collaboration networks at the three stages.

From 2005 to 2009, China had the world's largest number of patent applications in additive manufacturing with a total of 28 675, constituting 61.11% of the global total. The United States had a total of 7810, constituting 16.64% (Fig. 7). Although China had the largest number of patents in the world, the quality of patents still requires improvement. Therefore, China should continue increasing R&D investment to stimulate innovation capabilities to achieve independent control of core technologies and form international competitive advantages.

The patent collaboration of the additive manufacturing industry at the three stages was analyzed from the following two aspects.

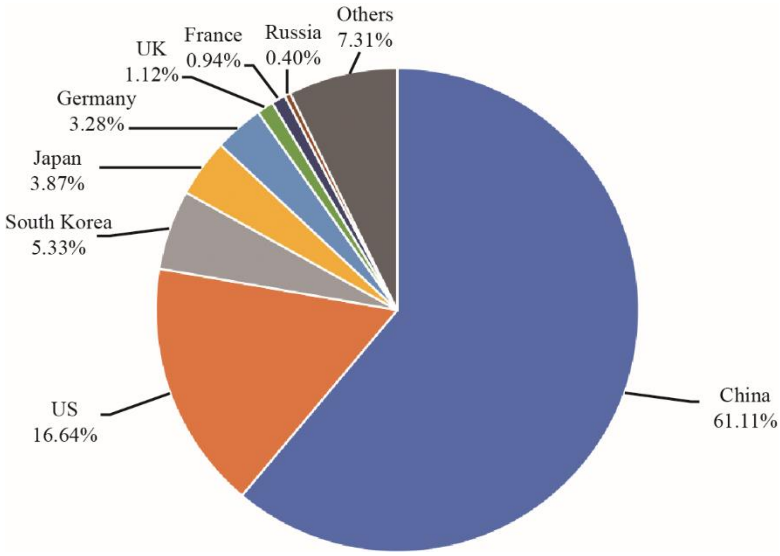

Fig. 7. Distribution of patent application in additive manufacturing industry during period 2005–2019.

Notes: The duration from patent application to successful retrieval was 18 months. Patent retrieval deadline was September 21st, 2019.

3.3.1 Global patent collaboration network of top 100 patentees

In terms of the number of patent applications, between 2005–2009 and 2010–2014, patentees owning the largest number of patents were concentrated in a few specialized additive manufacturing companies. However, in the third stage, traditional printer advantage companies and application companies were deployed in additive manufacturing, changing from users to equipment manufacturers or service providers. Consequently, the number of competitors increased and industrial competition worldwide intensified.

In terms of the global patent collaboration network of top 100 patentees, international patent collaborations at the three stages were few (Fig. 8) and decline gradually. This indicates that with the development of the industry, independent R&D and exclusive patent rights are preferred by the countries. In addition, collaboration among China's institutions increased significantly, indicating the considerable progress of the open innovation of China's institutions.

3.3.2 China's patent collaboration network of top 100 patentees

Regarding patentees, most foreign patentees were enterprises, whereas the majority of China's patentees were universities, which might be related to the evaluation mechanism of scientific research in China. Enterprises should be encouraged to participate in technological knowledge generation and to increase the pursuit of patent "quality" rather than only "quantity." From the perspective of China's patent collaboration network of top 100 patentees, patents with university–industry collaboration increased gradually (Fig. 9), particularly from 2015 to 2019. However, collaboration between universities and industry still require improvement. Most universities do not effectively collaborate with industry to form a complete "technology–business" chain, and this may cause scientific research achievements to remain only in laboratories. Therefore, China should continue promoting the breadth and depth of university–industry collaborations.

3.4 Business ecosystem

The market scale of the global additive manufacturing industry continued to expand steadily (Fig. 10). Prior to 2010, the global additive manufacturing industry was in its infancy, focusing primarily on scientific knowledge accumulation and technological exploration. It did not focus on commercial applications, and the market size was small. From 2010 to 2014, the scale of the global additive manufacturing market increased steadily by 30%. In 2012, the market size reached USD 2.3 billion, with a year-on-year growth rate of 35.29%. The growth rate decreased from 2015 to 2018, but it continued to scale. In 2018, the global additive manufacturing market reached USD 8.37 billion.

The commercialization of China's additive manufacturing industry began slightly later than developed countries,

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with a market size of only USD 160 million in 2012, constituting 6.9% of the global market. From 2015 to 2018, the growth rate of China's additive manufacturing market accelerated, nearly doubling the global average, and its share in the global market continued to increase. By 2018, the market size of China's additive manufacturing industry exceeded USD 2 billion, constituting approximately 25% of the global market.

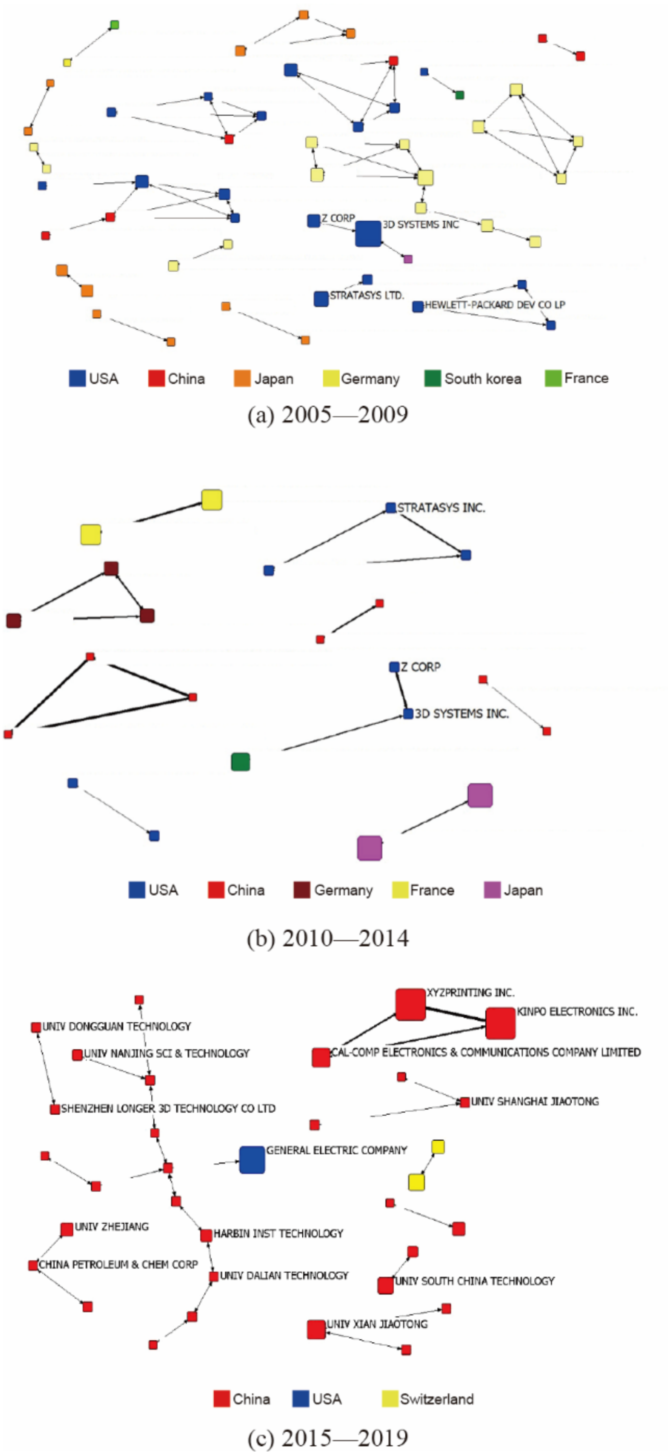

Fig. 8. Global patent collaboration network of top 100 patentees.

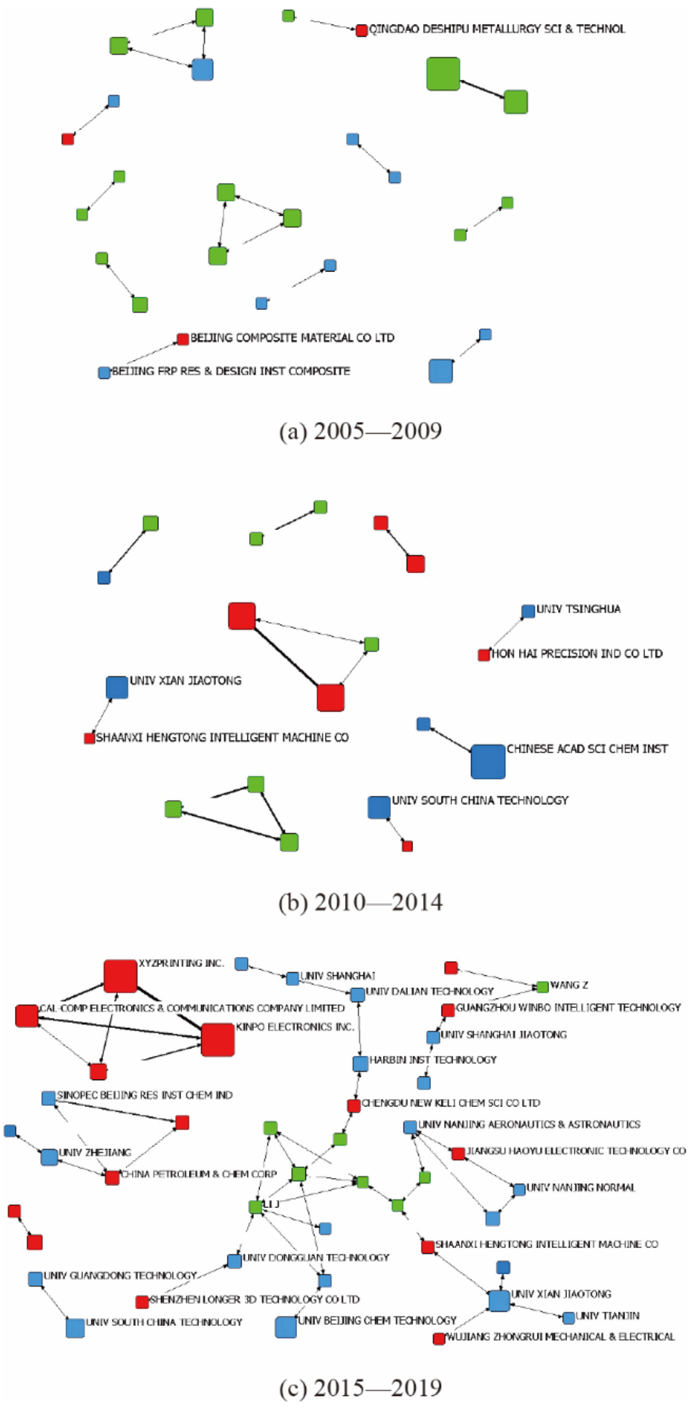

Fig. 9. China's patent collaboration network of top 100 patentees.

New installations in the global additive manufacturing are significantly demanded. From 1998 to 2016, the United States and China ranked first and second, respectively, in terms of number of new installations. However, from the perspective of commercial value creation, using the global additive manufacturing equipment production and sales in 2016 as an example, the United States ranked first, constituting 46.3% of the global market share, whereas China constituted only 4.5% of the global market share [12]. Therefore, despite the strong domestic market demand for the additive manufacturing industry in China, the commercial value-creation capabilities of relevant companies were relatively weak, and high-end equipment and materials were still mainly dependent on imports. A complete industry chain was not formed and industrial competitiveness was insufficient.

In terms of additive manufacturing application, the development status of the additive manufacturing industry

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in China is as follows: It moved gradually from scientific and technological R&D to industrial application, and the scope of industrial application became increasingly extensive (Fig. 11). Additive manufacturing is widely used in industrial machinery, aviation, aerospace, biomedicine, and other fields. However, owing to the production efficiency, R&D cycle, manufacturing cost, and other issues, the additive manufacturing production scale is small, and the gap to mass production is large. In addition, China's additive manufacturing enterprises are primarily small- and medium-sized enterprises, whose industrial design and manufacturing capacity are weak.

The distributions of various value chain segments in the material–design–preparation–application industry chain of additive manufacturing in China are imbalanced. Raw materials depend on imports to a certain extent; the product costs are relatively high, and the industrialization process is slow. The development of China's additive manufacturing industry is highly necessitated in the future. The industrial value chain must therefore be integrated with a particular focus on commercial applications and the enhancement of university–industry cooperation. Currently, the main body of scientific research activities in China's additive manufacturing industry are still dominated by universities and research institutes. This indicates insufficient intermediary services between the output of technology and commercial applications, which may result in the commercialization failure of numerous scientific and technological achievements.

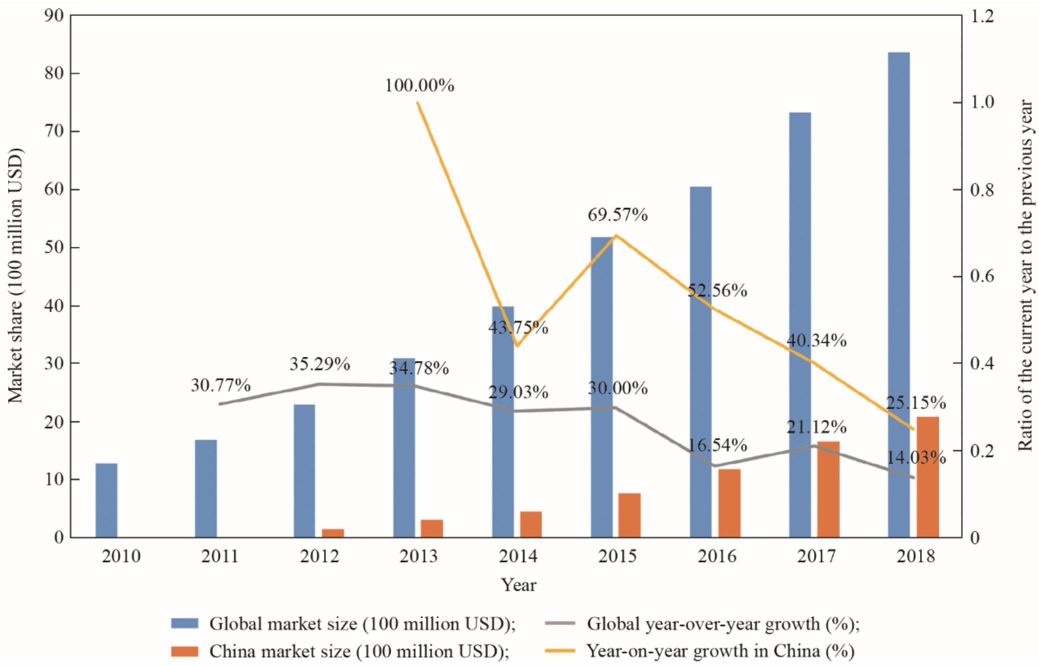

Fig. 10. Market scales of additive manufacturing industry worldwide and in China.
Source: *Global 3D Industry Report (2018–2023), Market Forecast and Investment Strategy Planning* by FORWARD Business Information Co., Ltd.

4 Co-evolution of policy and innovation ecosystems of additive manufacturing industry in China

4.1 Analysis of innovation policies

The implementation of innovation policies in China's additive manufacturing industry involves different emphasis at each stage.

4.1.1 Policy preparation stage (2005–2009)

At this stage, the concept of "strategic emerging industry" was demonstrated and proposed; however, the objective and direction of its development were not clearly proposed. At that time, the cultivation of strategic emerging industries was considered an important strategic decision for China's long-term development. Furthermore, the government proposed a strategic concept and a theoretical foundation for strategic emerging industries [13].

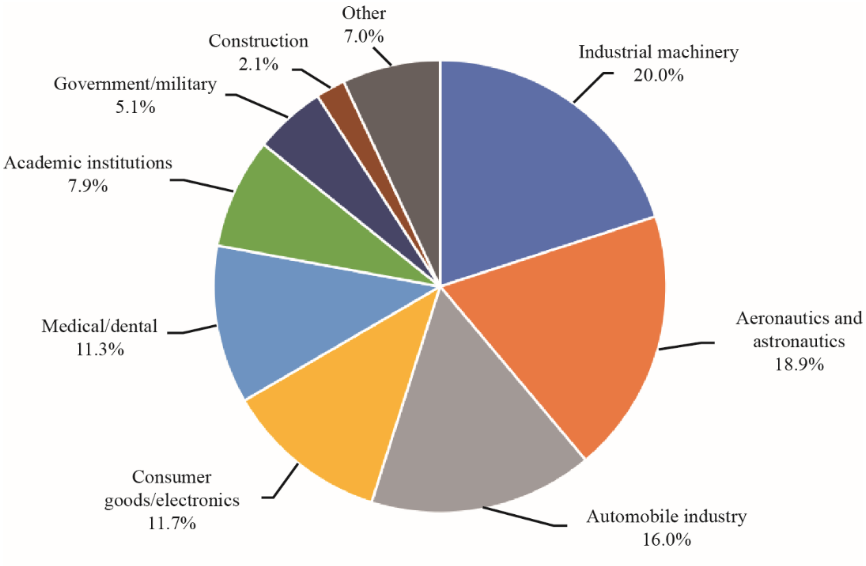

Fig.11. Application fields of China's additive manufacturing materials in 2018.

Source: Wohlers Report 2019.

4.1.2 Policy formulation stage (2010–2014)

At this stage, the national "strategic emerging industry" was upgraded to the national strategic level officially, in which development objectives and directions were planned overall. For example, in October 2010, the State Council issued the *Decision of the State Council on Accelerating the Cultivation and Development of Strategic Emerging Industries*, which determined the development goals, main tasks, and supporting policies of strategic emerging industries. In July 2012, the State Council released *The 12th Five-Year Plan for Development of Strategic Emerging Industries*, which identified mid- and long-term development goals, support policies, and major projects in seven key areas. In April 2013, the additive manufacturing industry was included in the strategic emerging industries for the first time in the *National High-Tech Research and Development Plan (863 Plan) and Guide for the Selection of Alternative Projects in Manufacturing Fields of the National Science and Technology Support Program in 2014* announced by the Ministry of Science and Technology.

4.1.3 Policy intensive stage (2015–2019)

At this stage, a series of policies related to the additive manufacturing industry were successively implemented, which provided clear guidance on the development objective and directions in this field, and a series of support and guarantee measures was proposed. To create a complete additive manufacturing industry chain of Material–Design–Preparation–Application, five key tasks, six safeguards, and five development goals were proposed in the *Additive Manufacturing Industry Development Action Plan (2017-2020)* issued by the Ministry of Industry and Information Technology, the Development and Reform Commission, and other 12 departments.

In summary, different types of policy tools place different emphases in the process of industrial evolution. According to the classification of policy tools, we categorized the innovation policies in China's additive manufacturing field (Table 1) and discovered that China primarily used supply-side and environmental policy tools to lead and promote the innovative development of the additive manufacturing industry.

4.2 Co-evolution of "policy–science–technology–business" in additive manufacturing industry

The development of China's additive manufacturing industry is a co-evolution process of policy, science, technology, and business.

In terms of policy tools, the government has implemented a series of supply-side, demand-side, and environmental innovation policies. Using policy tools comprehensively, the government promoted the additive manufacturing industry to improve the levels of scientific knowledge, technology, and market applications continuously to develop a healthy innovation ecosystem for the emerging industry at a faster pace.

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Table 1. China’s additive manufacturing innovation policy.

Policy document	Year	Supply type				Environmental type				Demand type	
		Talent training	Fund support	Technical support	Public services	Goal planning	Financial support	Regulation and norms	Property protection	Government purchase	Application demonstration
Decision of the State Council on Accelerating the Cultivation and Development of Strategic Emerging Industries	2010	✓	✓	✓		✓	✓	✓	✓		✓
The 12th Five-Year Plan for Development of Strategic Emerging Industries	2012	✓	✓	✓		✓	✓	✓	✓		✓
National Additive Manufacturing Industry Development and Promotion Plan (2015–2016)	2015	✓	✓	✓	✓	✓	✓	✓			✓
National Development Plan for Strategic Emerging Industries During the 13th Five-Year Plan Period	2016			✓		✓		✓		✓	✓
Special Plan For Science and Technology Innovation in Advanced Manufacturing Technology During 13th Five-Year Plan Period	2017			✓		✓		✓			✓
Application Guide for Key Projects of “Additive Manufacturing and Laser Manufacturing” in 2018	2017			✓		✓					✓
Action Plan for the Development of Additive Manufacturing Industry (3D Printing) (2017–2020)	2017	✓	✓	✓	✓	✓	✓	✓			✓
Catalogue of Key Support Industries for Intellectual Property (2018 Edition)	2018								✓		

In terms of science, China is continuously accelerating the investigation of basic scientific knowledge. By actively participating in international cooperation and absorbing overseas frontier knowledge, China can improve its position in cooperation gradually and achieve international integration in the shortest duration.

In terms of technology, as a latecomer country, China has a strong momentum to be on par with its competitors. The number of patent applications in China constitutes more than half of the total number of patents in the global additive manufacturing field. It is noteworthy that a wide range of patents exist, core patents are still limited. Hence, original technology must be developed. In addition, the cooperation between China's patent application agencies is primarily between universities and research institutes, and as such, cooperation among industry, universities, and research institutes must be encouraged.

In terms of business, the Chinese additive manufacturing industry has progressed considerably and has served the aerospace, industrial machinery, medical care, and automobile fields. Despite the expanding market in this field, the market potential is not completely exploited, and research results are not fully utilized. Therefore, transformation of results and commercial applications must be promoted.

The evolution of the industrial innovation ecosystem depends on the synergetic development of the science, technology, and business ecosystems. Scientific knowledge must be first transformed into technical strength and then into market value. However, weakness of any links may negatively affect the entire ecosystem. In general, the innovation ecosystem of the additive manufacturing industry in China has gradually improved (Table 2), whereas more effective and powerful measures to enhance value transfer to the market should be implemented in the future.

Table 2. Three-stage evolution of innovation ecosystem of additive manufacturing industry in China.

	Body	2005–2009	2010–2014	2015–2019
Policy	Government	Policy preparation stage: importance of strategic emerging industry was clarified.	Policy formulation stage: development objectives, major tasks, and specialized measures of strategic emerging industry were determined.	Policy intensive stage: a series of innovation policies for additive manufacturing industry were introduced.
Science ecosystem	Universities and research institutes	Universities and research institutes were primarily at the periphery of global scientific collaboration network. Scientific knowledge is limited.	Universities and research institutes gradually moved to the center of global scientific collaboration network. Density of collaboration network increased.	Universities and research institutes were more center in the global scientific collaboration network, with closer collaborations locally and abroad. Scientific knowledge dominated.
Technology ecosystem	Universities, research institutes, and enterprises	Most patent application institutions were universities and research institutes. Few collaborations among industry, universities, and research institutes.	Number of patent applications ranked first in the world. Lack of collaboration among industry, universities, and research institutes.	Number of patent applications was the highest in the world. Collaboration among industry, universities, and research institutes increased but still needs to be strengthened.
Business ecosystem	Enterprises	Industrialization level was relatively low. Market size was small.	Market size increased rapidly.	Market size continued growing.

In summary, through a systematic analysis of the evolutionary process of policy as well as the science, technology, and business ecosystems of the additive manufacturing industry (Fig. 12), we discovered that the development model of China's additive manufacturing industry was motivated by science and technology. In other words, China's universities and research institutes, in which scientific outputs are increasing rapidly, provide the motivation for the rapid growth of the additive manufacturing industry. However, related enterprises in the innovation ecosystem are scattered and relatively small-scale, and innovative achievements in science and technology cannot be transferred easily to the market. Therefore, the gap between R&D and industrialization in the innovation chain must be eliminated. In the development of industrial innovation, it is crucial to promote the better transformation of the outputs of universities and research institutes to the market. In addition, the flexible and full application of policy tools is important for realizing an efficient and sustainable industrial innovation ecosystem.

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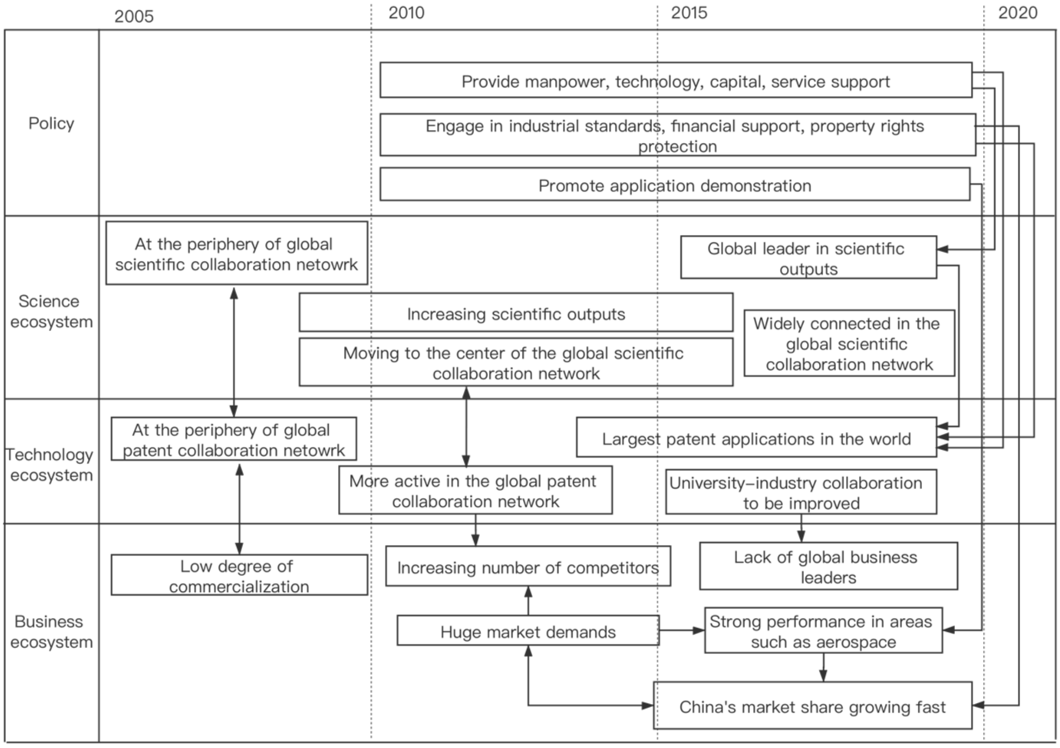

Fig. 12. Co-evolution of innovation policies and innovation ecosystem in China's additive manufacturing industry.

5 Conclusion and implications

From the perspective of the co-evolution of policies and innovation ecosystems, the overall development of the additive manufacturing industry in China has progressed significantly. Various policies and measures have been implemented to cultivate a healthy and sustainable innovation ecosystem. The levels of scientific output and technology development as well as the market scale have increased continuously. However, some shortcomings exist in the development of the additive manufacturing industry in China. Special materials and core devices depend on foreign imports to a certain extent. Furthermore, many scientific and technological achievements have not demonstrated commercial value. Downstream business models and application fields still require further investigation. China must build a comprehensive innovation ecosystem in which various innovation elements are fully used and efficiently configured. Hence, some policy suggestions for promoting the development of emerging industries are herein proposed.

5.1 Improve innovation capabilities of key sections along industrial value chain

Because the current high-technology imports are expensive and tend be restricted, it is crucial to enhance domestic research and independently realize controllable developments. Mastering key technologies can not only overcome technical obstacles such as materials and equipment, but also enable lower costs. Therefore, research support for key technologies in emerging industries should be continually increased and open innovation among various players should be encouraged. By focusing on critical science and technology development, we can further integrate the industry chain and improve international competitiveness.

5.2 Accelerate industrialization of scientific and technological achievements

To eliminate the gap between economy and technology and enhance the transformation of achievements, an effective intermediate link must be established between academia and industry. Hence, it is necessary to establish more intermediary service institutions, cultivate compound talents, and further improve the construction of public service systems, such as university science parks and enterprise incubators, to promote university–industry cooperation and accelerate industrialization.

5.3 Further investigation and expansion of application areas of emerging technologies

Emerging technologies in emerging industries can yield new solutions and advantages to various industrial fields, including traditional industries. The application areas of emerging technologies should be continually expanded such that the advantageous areas can promote economic development more effectively. To accelerate the transformation and upgrading of traditional manufacturing and achieve leapfrog development, it is necessary to investigate new models for the integration of emerging industries and traditional industries.

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