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A Case Study on the Mechanism of University-Industry Collaboration to Improve Enterprise Technological Capabilities from the Perspective of Capability Structure

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Abstract

Weak applied generic technological capability is the root cause for the hollowing-out of core technologies of industries in China, and the fundamental cause for the poor independent innovation and absorptive capabilities of the enterprise. This paper systematically analyzes the important role of university-industry collaboration in improving the corporate generic technologies based on the structure-conduct-performance (SCP) framework from the perspective of capability structure. Through theoretical derivation and analysis of the case of Kingfa, it proposes that the technological capability structure of enterprises has experienced an evolutionary process from "proprietary technology" to "proprietary technology and applied generic technology" and finally to "applied generic technology and basic generic technology" and that university-industry collaboration model correspondingly presents a change process from "auxiliary" to "complementary and auxiliary" and to "complementary", which positively affects the innovation output and the performance in the innovation process, showing a spiral escalation trajectory as a whole. Finally, it puts forward three policy optimization directions to help improve the enterprise generic technological capabilities: (1) further enhancing the corporate innovation capacity building and recognition of the position of entities, and establishing a multi-level university-industry collaboration system; (2) actively exploring new systems and mechanisms for the construction of high-end cutting-edge R&D institutions jointly participated by enterprises and universities; (3) promoting the comprehensive reform of the science and technology management system from aspects of market, finance and entrepreneurial environment.

Keywords

university-industry collaboration; generic technology; capability structure; SCP framework

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1. Introduction

The university-industry collaboration is an important means for the construction of a corporate generic technology innovation system. Affected by the industrial development model and enterprise technological capability structure, the university-industry collaboration in China is mainly used to solve the problems in enterprise basic generic technologies, and support and enhance the development of enterprise applied generic technologies. The enterprise technological capabilities can generally be divided into two categories: product design and manufacturing technological capabilities and generic technological capabilities, of which, the latter can be further divided into applied generic technological capability and basic generic technological capability. In reality, the enterprise technological capabilities are presented in a structural form, *i.e.*, the distribution structure of corporate product design and manufacturing technology, as well as generic technology. The technological capability structure of an enterprise must be adjusted accordingly in different development stages based on the dynamic changes and adjustments of strategies to meet the requirements of its strategic development. The development of university-industry collaboration is an important means for enterprises to improve and enhance their technological capability structure. Therefore, the enterprise technological capability structure is the starting and end point of university-industry collaboration.

In recent years, with the joint efforts of all parties, the university-industry collaboration has made great progress, which beneficially supports the solutions and improvements of corporate generic technologies. The practices of many enterprises in university-industry collaboration show that the goals and models of the corporate university-industry collaboration change dynamically according to the different development stages of the enterprise and the technological capability structure and level. It is necessary to promote the evolution of the technological capability structure of the enterprise while providing solutions and improving the enterprise generic technological capabilities to continuously develop and improve corporate generic technology innovation system. Therefore, the essence of university-industry collaboration to enhance the enterprise generic technological capabilities is that the matching degree of the capability structure (S) between the enterprise and the academic-research institution determines the university-industry collaboration (C) model and collaborative behavior. Different collaborative behaviors lead to different performances (P), and good performance promotes the continuous improvement of the capability structure of collaborative subjects.

According to the analysis above, this paper takes Kingfa's university-industry collaboration and development of generic technological capabilities as a case, deductively analyzes the mechanism of university-industry collaboration to enhance the enterprise technological capabilities and makes the following academic contributions:

(1) This paper puts forward the concept of the performance form and significance of enterprise technological capabilities based on the classification of generic technologies according to the analysis and research of China's situation and the research on the attributes and characteristics of "basic generic technology", "applied generic technology" and "proprietary technology", and accordingly points out that the weak applied generic technological capability is the root cause for the hollowing-out of core technologies of industries in China;

(2) The improvement of technological capabilities is the foundation for enterprises to seek for university-industry collaboration and innovation. The innovation capability structure and level of collaborative entities have an important impact on the motivations and behaviors of collaborative

innovation. This paper explains the current problems and predicaments in innovative development of university-industry collaboration in China from the perspective of the innovation capability structure, and ushers in a new framework for exploring and solving the practical and theoretical problems in the innovation of university-industry collaboration.

2. Literature Review

2.1. Structural dimensions of enterprise technological capabilities

The academic circles have never stopped discussing the structural dimensions of enterprise technological capabilities since the 1880s. From the perspective of functions, scholars believe that enterprise technological capabilities are the ability of an enterprise to realize or complete technology-related activities. For example, Lall (1992) divided the structural dimensions of technological capabilities into three elements: investment capability, production capability, and technology commercialization capability; Kim (1997) divided the structural dimensions of technological capabilities into three elements: production, investment and innovation. From the perspective of process, scholars divide the dimensions based on the role of technological capabilities in technological change. For example, the technological capability structure was divided into public welfare acquisition, process operation, process transformation and product transformation by Gammeltoft in 2004, and into technology identification, technology migration and technology processing capability by Tang *et al*. in 2016. From the perspective of knowledge, scholars link the capacities with the knowledge stock, and believe that technological capacities are the sum of technologies and knowledge in stock of an enterprise. For example, Ernst *et al*. (1998) believed that the dimensions of enterprise technological capabilities include the sum of knowledge and skills required to acquire, absorb, improve and create technologies, and Zhao and Xu (2002) considered the technological capacities as the sum of the knowledge and skills of an enterprise in terms of technological activities and technological resources.

From the perspective of university-industry collaboration technology supply structure, technologies can be divided into proprietary technology and generic technology according to the public goods attributes and development stages, and generic technology can be further divided into applied generic technology and basic generic technology. Proprietary technological capability (product design and manufacturing technological capabilities, *i.e.,* the secret technological knowledge and technological experience of an individual enterprise and their accumulation) is the technological capability of an enterprise that can be directly used to develop and manufacture products based on generic technology and in combination with enterprise background and actual application (Zhu, 2012; Bi *et al*., 2012). Applied generic technological capability refers to generic technologies with moderate secondary development applied close to the market, developed on the basis of basic technology in combination with industry or industrial background and needs, generally applied in a single or multiple industries (Tassey, 2004; Li, 2011). Basic generic technological capability refers to generic technologies close to basic research with prominent systematicness, scientificity, integrity and fundamentality that requires a long-term secondary development before commercial application and can be applied in multiple industries or fields and whose R&D and innovation are derived from the long-term accumulation of basic theories (Tassey, 1991; Huang, 2016).

In different development stages, the enterprise has different degrees of mastering the three technological capabilities and presents the characteristics of different structural forms. Corporate strategies are changing dynamically and under constant adjustment according to the increasing market and development, which in turn puts forward higher requirement on the level of capability structure. If the current technological capability structure of an enterprise cannot meet this requirement, university-industry collaboration will be an important and effective measure to compensate for structural imbalance.

2.2. Study on the mechanism of university-industry collaboration to improve enterprise technological capabilities

In the context of a higher level of industrial technology, university-industry collaboration in western developed countries is more likely to take place in the early stage of innovation where the cooperative innovation dominated by applied generic technology and basic generic technology can easily enable both parties to establish a strategic partnership to achieve mutual complementarity and the objective of the entity and the cooperative objective are convergent in most cases. Therefore, the studies on the mechanism of university-industry collaboration in foreign countries are more about the exploration of the university-industry interaction model selection, trust mechanism, cross-border cooperation mechanism and knowledge transfer mechanism. Among them, scholars believed that in the process of model selection, innovation capability is a key factor, and enterprises tend to choose appropriate university-industry collaboration models based on their own innovation capabilities and innovation strategies (De Fuentes and Dutrénit, 2012). Hemmert (2014) pointed out that, in the process of establishing a trust mechanism, compared with developed countries such as the United States and Japan, emerging developing countries pay more attention to the early reputation and the leadership of innovation champions. The cross-border cooperation mechanism included the adjustment of requests, needs, capabilities and attitudes of all parties (Chau *et al*., 2017), which can better enhance the sustainability and success rate of the university-industry collaboration under the premise of matched needs, collaborated capabilities and consistent attitudes. In terms of knowledge transfer mechanism, scholars emphasized that continuous interaction between industries and academic circles is the best way to transfer knowledge (Nielsen and Cappelen, 2014; Motoyama, 2014), and a good knowledge transfer mechanism plays an important role in the improvement of corporate capabilities and performance. In the meantime, foreign researchers have begun to pay attention to the differences between developed and developing countries in the process of university-industry collaboration. For example, Mgonja (2017) provided a variety of useful suggestions for developing countries to tackle the dilemma of university-industry collaboration after combing and summarizing the accumulated experience of developed countries in scientific research cooperation. According to an analysis of 68 key foreign documents based on the literature reviews on university-industry collaboration, accompanied by those of Faisal *et al*. (2017), Garousi *et al*. (2016), Ankra and AlL-Tabbaa (2015), and Perkmann *et al*. (2013), Nsanzumuhire and Groot (2020) found that compared with developed countries, the study coverage in developing countries is yet to be developed, and suggested that behavioral study methods should be adopted to promote the study on university-industry collaboration in developing countries.

Since most enterprises in China are weak in technological capacities, they are weak in the development of proprietary technologies and less capable of undertaking the secondary development of basic generic technologies in university-industry collaboration. Different from the technological development path of western developed countries who use university-industry collaboration to solve forward-looking technological problems from the breakthroughs in generic technologies to the cultivation of corporate technological potential and then the diffusion of proprietary technologies, China, as a big late-developing country pursuing import substitution and export-oriented catch-up strategy, has a reverse path of introducing generic technologies and foreign investments to directly form proprietary technologies (Zhou and Ding, 2011). The university-industry collaboration stresses more on the solution to the existing product development needs of enterprises, ignoring support for the improvement of generic technologies and enterprises' independent innovation capabilities, resulting in an imbalance in the capacity structure and the inefficient improvement of independent innovation capabilities. Therefore, the exploration of university-industry collaboration in the Chinese context is of great theoretical and practical value to improve the enterprise technological capabilities (Nsanzumuhire and Groot, 2020).

The current domestic studies on the effect of university-industry collaboration to improve enterprise technological capabilities are more about the impact of motivation matching, technological gap, cooperation model and knowledge coupling between enterprises and academic research institutions on improving enterprise technological capabilities and performance. For example, Sun (2016) found from the perspective of motivation matching that the motivation matching of university-industry collaboration has a significant positive impact on the main collaborative behaviors (resource investment, communication, organization and decision-making) and performance. Jiang (2018) found through empirical research from the perspective of technological potential difference that in the collaboration between low-potential enterprises and high-potential academic and research institutions, enterprises can evidently improve their technological capabilities in the short term but the long-term effect is less noteworthy, while in the collaboration between high-potential enterprises and low-potential academic and research institutions, the existence of the reverse technological gap can even significantly inhibit the long-term growth of the enterprise technological capabilities. Zhao and Xu (2002) divided technological capabilities into three levels: technology acquisition capability (imitation capability), technology assimilation and absorption capability (creative imitation capability), and technology innovation capability (independent innovation capability) and studied the important role of university-industry collaboration in enterprises' spanning different capacity levels and improving technological capabilities (Liu, 2013).

Currently, the study on the relationship between university-industry collaboration and the improvement of enterprise technological capabilities is still in the stage of feature mining and linear relationship analysis, lacking logical thinking of dynamic evolution and exploration of multi-dimensional structure mechanism. According to the status of enterprise development and innovative development of university-industry collaboration in China, and based on the theory of technological capabilities, it is believed that the structure of enterprise technological capabilities is the start and end of university-industry collaboration, and the mismatch in capacity structure between the collaborative subjects is a major cause for poor collaboration, downward shift of cooperation focus, and loose collaboration form. From the perspective of innovation capability structure, the paper proposes the SCP theoretical framework for university-industry collaboration innovation, further analyzes and demonstrates the mechanism of interaction between university-industry collaboration and improvement of enterprise technological capabilities through case studies, and makes possible breakthroughs as follows:

(1) It summarizes the structural dimensions of enterprise technological capabilities and their evolutionary laws, *i.e.*, the process from proprietary technological capability to the coexistence of proprietary technological capability and applied generic technological capability, and finally to the coexistence of proprietary technological capability, applied generic technological capability and basic generic technological capability.

(2) It studies the case based on the SCP theoretical framework, systematically analyzes and further explores the evolution path of the technological capabilities of Kingfa Sci. & Tech. Co., Ltd., selection

of university-industry collaboration model and changes in performance, and abstracts the co-evolution models of enterprise technological capabilities, university-industry collaboration model and performance in different stages;

(3) By cross-stage comparison, it abstracts the spiral dynamic evolution track of the improvement of enterprise technology capabilities by university-industry collaboration, namely, the structure of the enterprise university-industry technological capabilities varies from "proprietary technology" to "proprietary technology and applied generic technology" and finally to "proprietary technology, applied generic technology and basic generic technology" and the collaboration model presents a change from "auxiliary" to "complementary and auxiliary" to "complementary", and concludes that the technological progress, benefit improvement and innovation process performance obtained at each stage will provide technological support and resource support for improving capacities in the next stage.

3. Study Design

This paper studies a typical enterprise in an exploratory manner based on the SCP theoretical framework composed of enterprise technological capability structure, university-industry collaboration model and cooperation performance, and gradually develops the three development stages of the enterprise into three independent and interrelated research units. This study is proper as, first of all, it focuses on the co-evolution process of the university-industry collaboration model and the enterprise technological capability structure and properly uses a case study method that pays close attention to "how" and stresses on the "process" inquiry (Yin, 2002). Second, since the technological capability structure, university-industry collaboration model and their co-evolution are complex and change dynamically in different development stages of the enterprise, by single-case study, the process can be carefully tracked and the evolution can be analyzed (Buckley *et al*., 2005), and further a new theory independent of existing literature or previous experience can be built (Eisenhardt and Graebner, 2007). The single-case study is also conducive to controlling other influencing factors and identifying causal relationship, so that the relationship and influencing mechanism between the two can be further understood. Besides, by exploratory single-case study, the key features and events can be put in order and the dynamic and systematic process can be explored (Luo *et al*., 2015).

3.1. Case selection

The paper follows the principles of theoretical sampling and purposive sampling, considers the typicality of the case, the availability of data and the convenience of study, and finally takes Kingfa Sci. & Tech. Co., Ltd. (hereinafter referred to as Kingfa) as the sample for case study. In terms of the typicality of the case, Kingfa is a technology-based listed company specialized in the research and development, production and sales of high-performance modified plastics that has established different types of collaborative relationships and models with top universities and well-known companies in the industry chain at home and abroad since its establishment in 1993. Consequently, its technological capability structure has undergone a co-evolution process from the proprietary technology improvement to the generic technology improvement. Therefore, Kingfa makes a good study sample for us to explore the needs of enterprises for technological capabilities in different stages, the university-industry collaboration models for enterprises with different technological needs to better improve performance, and the role and effect of different university-industry collaboration models on improving enterprise generic technology. In terms of data accessibility and study convenience of the case (Yan and Gray, 1994), Kingfa has been under observation and study since April 2013, and a large number of first-hand in-depth interview data around the study on "university-industry collaboration and improvement of enterprise generic technological capabilities" has been obtained. Besides, as one of the companies with the most complete varieties of modified plastics in the world, Kingfa has attracted the attention of academic circles and news media both at home and abroad, so related study results and reports can be collected and obtained from multiple channels.

3.2. Data collection and analysis

3.2.1. Data collection

The data are sourced from various channels, mainly including: (1) the in-depth semi-structured interviews. The research team has had multiple in-depth interviews with Kingfa from 2013 to 2020; (2) internal archives of the enterprise, including corporate meeting minutes, annual summary, etc.; (3) external data, including official corporate information, published research reports, annual reports, relevant documents, and relevant news reports, etc.; (4) participant observations, like visiting the enterprise exhibition hall and participating corporate meetings and project activities, etc.; and (5) informal acquisition channels, for instance, e-mail, phone, video meeting, etc., among which, the in-depth semi-structured interviews are the main source channel for this paper.

3.2.2. Data analysis

In order to ensure the quality of data coding and analysis, the following strategies are taken to render certain validity and reliability of the research: (1) Formulate a detailed research proposal and conduct repeated demonstrations on the contents and feasibility of the proposal by 3 professors experienced in the research of university-industry collaboration and case studies before research; (2) Though data analysis depends on multiple sources, different types of data must be able to converge under data triangulation and reach the same conclusion; (3) Conduct the pretesting reliability test. To be specific, randomly select 10% of the text, encode independently by three doctoral candidates, and carry out the consistency test according to the mutual agreement degree and reliability formula proposed by Holsti; (4) In the process of data analysis, pay attention to the constant deliberation on data, materials, theoretical logic and documents, gradually present the logic and path matching for data and theories in the continuous deduction and exploration, and enhance the theoretical refining and abstraction, so as to draw more applicable and generalized conclusions.

4. Case Description

Founded in 1993, Kingfa is a listed technological enterprise engaged in research and development, production and sales of high-performance modified plastics, and has developed over 4000 brands of independent intellectual property products, including biodegradable plastics, obtaining various national awards. Moreover, the company sells its products to more than 130 countries and regions in the world owing to its high environmental-friendly degree and excellent performance and provides services to more than 1000 well-known enterprises around the world. It is not only a national leading enterprise of modified plastics, but also a world leader in modified plastic products. The result of coding is as follows (Table 1 and Table 2).

Starting up the business with the patent of "flame retardant and high impact polystyrene masterbatch", it learned from similar products of multinational companies by imitation at first to acquire the ability

Table 1 Example of open coding

Typical Reference	Concept	Category
Kingfa tackled key core technologies through the university-enterprise joint laboratory, solving a great batch of problems in major industrial key generic technologies (2016c).	a1 Establishment of a joint laboratory	A1 Fundamental research
Kingfa had established long-term and stable cooperative relations with more than 20 key universities at home and abroad, such as Beijing Institute of Technology, and more than 10 well-known domestic research institutions such as the Chinese Academy of Sciences. It had also established research bases and co-built university-industry collaboration bases to break through basic generic technologies through fundamental research (a).	a2 Long-term stable cooperation	
……	……	
The research on thermotropic liquid crystal polymers (TLCP) started late in China and the technology is relatively backward. At present, most of TLCP demanded in the domestic market are imported. In order to break the technical monopoly, Kingfa has cooperated with colleges and universities to start the research on TLCP, breaking through the key technology of TLCP production. The technology was applied for more than 20 invention patents, 4 of which were authorized (b).	a6 Extraction of basic principles for technical design	A2 Application-oriented exploratory learning capacity
Kingfa, taking the domestic demand of polypropylene material in the automobile industry as a pointcut, has concentrated superior resources and broken through multiple technical difficulties through years. Innovations and major breakthroughs have been made in five key technologies of automotive polypropylene materials, and a series of high-performance environment-friendly polypropylene products for automobiles have been developed (b).	a7 Application research of fundamental research	
Carbon fiber technology was introduced from the Institute of Chemistry, Chinese Academy of Sciences, and involves some basic generic technologies. Based on this, we carried out secondary development (a).	a8 Secondary integrated development of basic generic technologies	
In 2004, we have established the Management Institute of Kingfa and we hope to better realize the communication between senior R&D and management personnel and reach a higher management level (a).	a9 Personnel interaction	A3 Searching capacity of basic knowledge
Universities and some research institutes, such as the Chinese Academy of Sciences, are important sources of information about our basic generic technologies and some key technologies (a).	a10 Education and research information platform	
……	……	
Kingfa developed new products and new markets to seek transformation by keeping track of the market dynamics (2012c).	a34 Market-oriented new product development	A9 Product marketability
Kingfa entered the European market for fully biodegradable materials and obtain CEN13432 biodegradable product certification (2014c).	a35 New market exploitation	

Note: Category "a" data are from the research and interviews of project team members, category "b" data are from all kinds of second-hand resources (not including newspapers and periodicals) and some text resources provided by the Company, and category "c" data are from a large number of newspapers and periodicals with dates.

Table 2 Axle coding results

Sub-category	Secondary category	Main category
A9 Product market capacity	b1 Product design capability	B1 Proprietary technological capability
A4 Product conceptual competence		
A5 Product innovation capability		
A13 Process development capability	b2 Process manufacturing capacity	
A7 Manufacturing capacity		
A10 Capture capability of demands of downstream customers of the industry chain	b3 Industrial chain integration capability	B2 Applied generic technological capability
A11 Cooperative R&D capability of upstream suppliers of the industry chain		
A12 Basic oriented developmental learning capacity	b4 Dual learning balance capacity	
A2 Application-oriented exploratory learning		
A6 Strategic cooperative capability in fundamental research	b5 Cooperative capability in fundamental research	B3 Basic generic technological capability
A1 Organizing and cooperation capability in fundamental research		
A2 Searching capacity of basic knowledge	b6 Explorative learning capacity	
A8 Sharing capacity of basic knowledge		
A14 Integrating capacity of basic knowledge		

of technology commercialization. In 1998, as the grand vision of "create the world brand with endless development" brought out by the general meeting of shareholders, Kingfa started to change from imitating to creatively imitating. In 2012, Kingfa put forward the strategic goal of "becoming the world's most excellent material enterprise with high respect in the industry", which marks the transformation of Kingfa's strategy from creative imitation to independent innovation. Since then, it has become an innovative enterprise.

According to the technical capacity development strategies and major milestones, the development of Kingfa is divided into three stages in this paper: Imitator stage (1993-1998), Follower stage (1999-2012) and Parallel runner stage (2013-).

4.1. Imitator stage (1993-1998)

Kingfa started its business with a patent of proprietary technology - "flame retardant high-impact polystyrene masterbatch". With this technology, Yuan Zhimin and his team started the research, development and production project of high-performance modified plastic products in a simple room with 20m^2 in Guangzhou, initiating the start-up stage of Kingfa. In order to achieve sustainable patented technology, the enterprise must practice the technology to products and put the products into the market to generate economic benefits through production and operation. Therefore, the key is to seek ways to transform production and commercialization. Yuan Zhimin and his team improved the ability of technology commercialization transformation in the process of "learning via imitation" by imitating similar products: In 1994~1995, Kingfa conducted reverse engineering on similar products of transnational

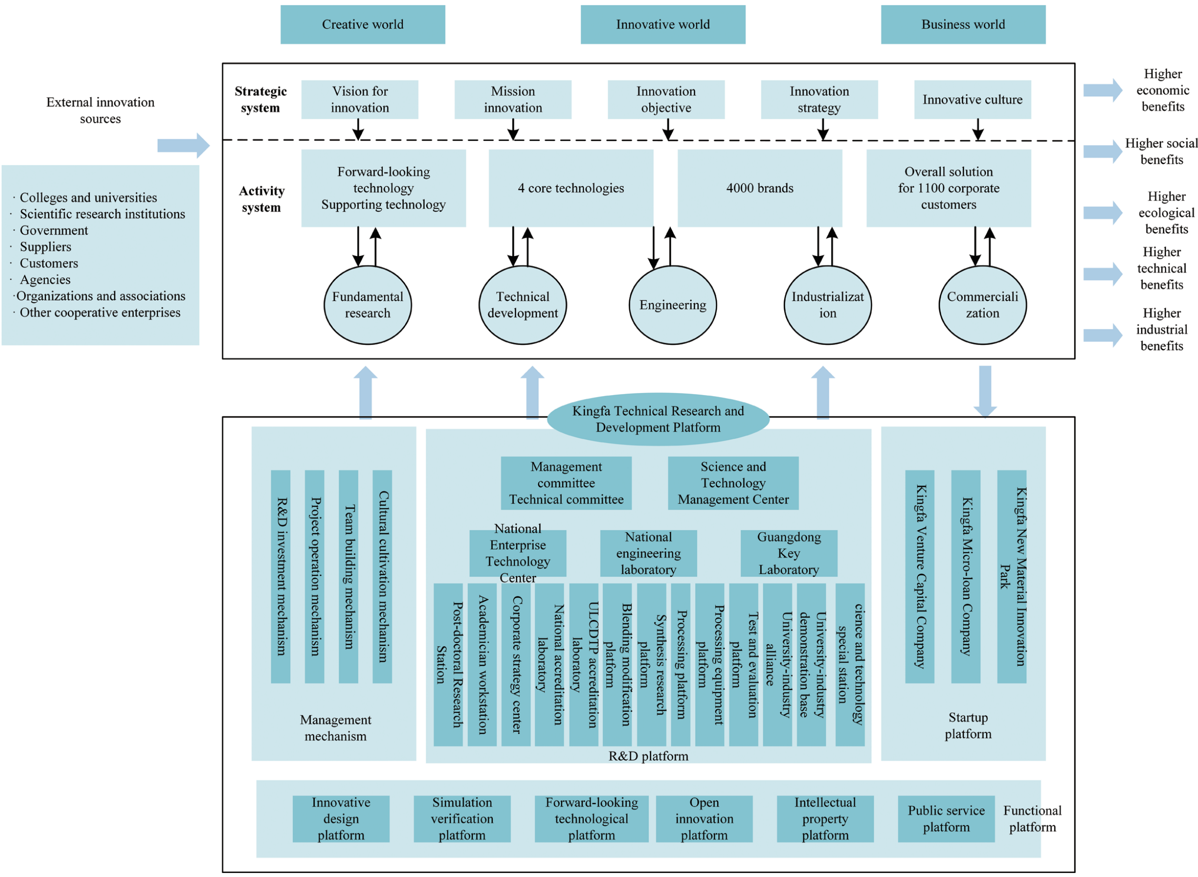

Fig. 1 Comprehensive innovation ecosystem of Kingfa

enterprises and obtained the formula for imitation. Meanwhile, it has carried out short-term cooperation with Sun Yat-sen University on the product production process and existing technology improvement, and successfully completed the productization process of flame retardant HIPS technology (Figure 1).

4.2. Follower stage (1999-2012)

At that time, Kingfa did not set up an R&D department, and only three doctoral-degree holders in the research team were able to carry out the research and development of relevant technologies. Moreover, it lacked the necessary instruments and equipment for technical development. In such a context, Kingfa paved its way for scientific research through cooperation and innovation. In order to acquire knowledge related to technology development, Kingfa has successively established project cooperation relations with such universities as Beijing Institute of Technology and Sichuan University. The research on technology improvement and the application were carried out for HIPS and PP technologies and it obtained the first invention patent in 1998 — halogen-free low smoke flame retardant thermoplastic polyolefin complex and its preparation method. In 2000, the invention patent of polypropylene composites for outdoor use was applied, and in 2004, the polypropylene resin composite material and its injection molding products which can replace HIPS and ABS abrasive tools and are used in the housing of household or office electrical appliances were invented, whose molding property, rigidity toughness and molding shrinkage are all better than other existing products.

After 2000, in order to further correspond to the market demand and technological development, Kingfa, by focusing on establishing cooperative relationships with industrial chain enterprises, has gradually cooperated with domestic and foreign enterprises that are upstream and downstream customers of the industrial chain, such as Sichuan Changhong, SONY and Ford, and keep abreast of market demand and trends to control the product and technology development direction. In 2003, Kingfa established a Post-doctoral Research Station which was recognized as a national technological center in the same year. After 2004, Kingfa invested RMB 15 million to the research of the university-industry collaboration projects every year, and developed the international advanced material preparation technology for nano-calcium carbonate breathable composite and fully biodegradable plastics, which bridged the gap in the country. In 2006, Kingfa signed a cooperation framework agreement respectively with School of Chemistry and Chemical Engineering of Shanghai Jiao Tong University and Shanghai University, thus making the university-industry collaboration more formal. In 2008, Kingfa has obtained the National Engineering Laboratory for Plastic Modification and Processing granted by the National Development and Reform Commission. In 2009, Kingfa has carried out the university-industry collaboration with Beijing University of Chemical Technology and established a personnel and technology exchange platform. In the same year, it also built the first UL-approved material long-term thermal aging laboratory in Greater China, which provided conditions for the applied research and experimental development of its generic technologies. In 2010, Kingfa joined the modified plastics industrial technology innovation strategic alliance whose members were the colleges and universities, research institutes, industrial competitors, upstream and downstream enterprises and governments, etc. With the support of the alliance technology, Kingfa established "Shanghai Engineering Technology Research Center of Modified Plastics Industry" and conducted further development of industrial generic technologies, which promoted the development and innovation of technological systems in the alliance and related industrial chain.

4.3. Parallel runner stage (2013-)

In 2013, Kingfa set up a scientific research team consisting of 5 experts with special subsidies from the State Council, more than 100 doctoral students and 350 postgraduates, and an expert advisory group consisting of 12 academicians and 35 senior experts at home and abroad, with strong knowledge acquisition and transformation and application ability, by which, the ability structure has also been optimized. In the same year, as a leading enterprise in the industry, the Company took the lead to construct a "Technical Committee Branch of Modified Plastics of National Technical Committee for Standardization of Plastics". In 2015, Kingfa was registered in Michigan, the United States, so as to better connect with the fundamental research and the basic generic technology, and introduce high-level overseas talents in China. In 2016, Kingfa signed a technical assistance agreement themed on "Innovation-driven development & strategic alliance" with China Jushi to jointly conduct R&D and innovation to meet the individual needs of customers in the thermoplastic industry. In 2018, the thermoplastic composites automobile lightweight products of Kingfa Carbon Fiber Company were put into mass production successively, which was the first time in the field of lightweight of automobiles, thus gaining high recognition from the main plant, Ford. In 2019, the Company marched its way to the upstream of modified polypropylene through Ningbo Kingfa Project, gradually breaking through the whole industrial chain of propane-propylene and polypropylene. In the first half of 2020, the Company has seized the opportunity to extend to the downstream application of modified polypropylene to expand the medical and health business, broadening its application fields for the Company.

According to the above analysis, in addition to continuing to conduct the R&D and application of proprietary technology and applied generic technologies, Kingfa also started to get involved in the R&D of basic generic technologies to provide better support for the first two technologies to cope with the changing market.

5. Findings on Cases

5.1. Effect of university-industry collaboration on the improvement of technological capabilities in different development stages

5.1.1. Imitator stage: improvement and completion of proprietary technology

Incipience (strategy and capability requirements): In the start-up stage, the key issue for Kingfa is to survive. Hence, in order to survive in the new technological or market field and improve the position in the industry as soon as possible, the senior management put forward the development goal of "learning from similar products via imitation and quickly applying the technologies to products". To this end, the company chose to carry out reverse engineering on similar products of multinational companies, namely, flame retardant HIPS technology, and quickly practiced the flame retardant HIPS technology into products via imitation.

Imbalance (problems and cross-boundary searching): In the process of imitation, Kingfa is limited by technology, talents, equipment and other resources. In terms of technology, its production and manufacturing capacity was relatively weak: in terms of talents, the majority of its employees was marketing personnel, lacking high-level technical personnel; and in terms of equipment, it had no production equipment of its own till 1995. With its own ability, it was not enough to complete the whole process of technology productization, and there was still a gap between the competence level and the goals to be achieved. Therefore, in the process of reverse engineering to achieve technology productization, after encountering technical problems that cannot be solved by themselves, the enterprise was to resort to external forces.

Cooperation (mode selection and path): Kingfa chose to cooperate with Sun Yat-sen University to tackle the problems encountered in the production and manufacturing process through university-industry collaboration, and realized the transformation from technology to products with physical modification. Thus it can be seen that Kingfa has begun to make up for its shortcomings in technical capability structure with the help of external forces. However, at that time, Kingfa was feeble in its own ability, without a good understanding of the corresponding technological research and development and manufacturing process. Therefore, all about the university-industry collaboration was mostly carried out in short term, in which, consultation and communication were mainly carried out for the solution of specific problems in production. Although this form of collaboration was at a low level, it is important for Kingfa to accumulate its own technical strength.

Results (capability and performance improvement): The key to the process was to improve the production capacity, which was conducive to expanding the depth of internal knowledge of the enterprise. In terms of product capability improvement, by continuously improving the production process and performance of HIPS technology, Kingfa has extended its application fields from audio to TV, computer, air conditioning, etc. In terms of enhancing R&D capability, the high-density PP materials developed by the Company successfully substituted the imported materials, reducing the cost of over RMB 10,000,000 for Sichuan Changhong Company in 1997, and brought profits to the Company in the same year. In 1998, the Company passed the certificate of quality system ISO9001. However, this mechanism can only partially release the constraint on enterprise resources and has a slight effect on the development of industrial technology. Due to the short term of university-industry collaboration and the low-level technology, although it was beneficial to accumulate the enterprise's technical strength, it cannot improve the generic technical ability of the enterprise, with poor innovation sustainability (Figure 2).

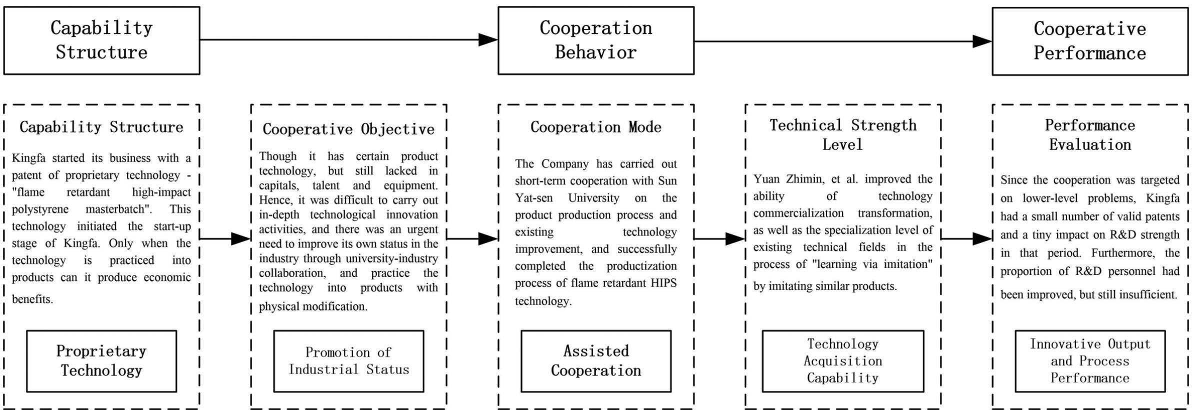

Fig. 2 Effect path of "structure – cooperation - performance" in imitator stage

5.1.2. Follower stage: exploration and application of applied generic technology

Incipience (strategy and capability requirements): In 1999, after new products achieved certain benefits, Kingfa was no longer satisfied with pure product design and manufacturing, and hoped to enhance the competitiveness of its products by promoting research and development. At that time, the senior management put forward the grand vision of "create the world brand for hundreds of years of development of Kingfa" and wished to promote the research and development to improve the competitiveness of the products. In the course of technological development, it proposed to transform from imitation strategy to creative imitation strategy, and in 2005, it first proposed the strategic goal of transforming from follower to leader. For this goad, Kingfa began to focus on the construction of technological centers and innovation platforms, the introduction and training of talents, and the sustainability of university-industry collaboration in terms of institutional construction, and in technological development, it gradually marched to the upstream technology of the industry chain, such as special engineering plastics, biodegradable plastics, etc.

Imbalance (problems and cross-boundary searching): At that time, the enterprise already had the relatively perfect proprietary technological capability, also began to step in the mining of some applied generic technologies. In spite of this, in product development, the focus was mainly on serialization and imitative innovation, and the key to the university-industry collaboration mode is mainly the technological breakthrough. As it lacked experience in the development and application of technological capacities and the expansion of the technological field, it is necessary for the company to rely on external forces to assist the exploration of technological expansion.

Cooperation (mode selection and path): In order to implement the creative imitation strategy, Kingfa did not choose technologies too inclined to the fundamental research. Instead, it chose technologies that are closely related to its existing products and technologies. Moreover, they were difficult to be broken through, but realistic and feasible involving a wide range of aspects. Although they did not realize that this was the applied generic technology at that time, they understood that what they needed to break through at that moment was the technology behind the proprietary technology, that is, to research and develop the applied generic technology by relying on the existing product design capability and process manufacturing capacity through the in-depth university-industry collaboration. In 2006, Kingfa co-built the innovation platform with Sun Yat-Sen University to cooperate for the breakthrough of high-performance high polymer materials technology. In 2009, it cooperated with the University of Science and Technology of China on the research and development of halogen-free flame retardant technology and product development of engineering plastics. In 2010, it cooperated with Sun Yat-sen University on the industrialization of high-performance carbon fiber composite materials. In 2011, it has established deep technical cooperation relations with more than 20 key universities such as Beijing Institute of Technology, Sichuan University, Chinese Academy of Sciences and Chinese Academy of Engineering, more than 10 well-known domestic research institutions and more than 20 multinational institutions.

Results (capability and performance improvement): Through the development in this period, Kingfa had formed five series of product lines concerning flame retardant resin, reinforced and toughened resin, plastic alloy, functional masterbatch and degradable plastic in terms of technical capability improvement, and had rich knowledge and experience in such core technologies as alloying and plastic alloy technology, flame retardant technology and thermoplastic elastomer technology. In terms of platform capability improvement, it set up Guangdong Kingfa Key Engineering Technology Research Center in 2000, got the approval to set up a Post-doctoral Research Station in 2003, set up the academician workstation in 2004, and Kingfa Research Institute in 2007. As for innovation output, it has won 8 awards for scientific and technological progress, technological invention and excellent patent at national, provincial and municipal levels. In 2004, it established the first national enterprise technology center in the industry, and in 2006, it established the first national recognized laboratory in the industry. Speaking of technological accumulation, the Company has accumulated 120 patents, including 88 invention patents (Figure 3).

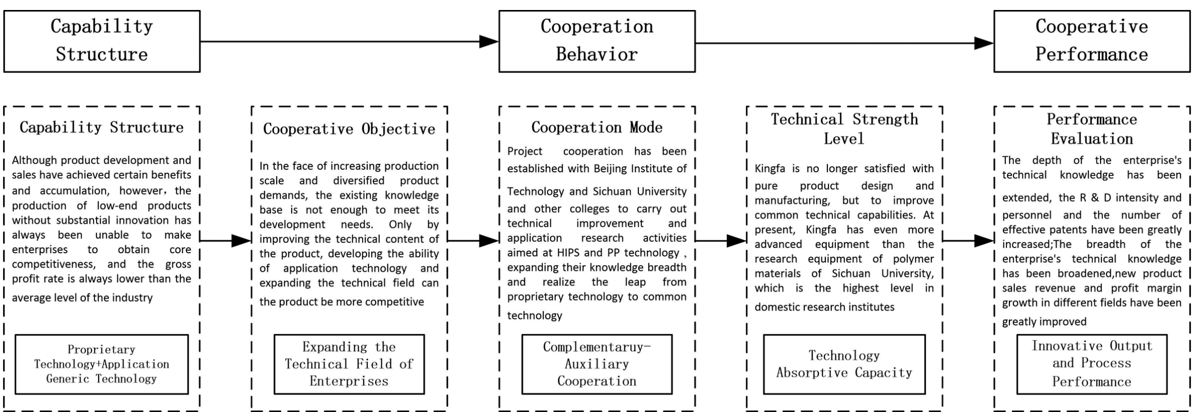

Fig. 3 Effect path of "structure – cooperation - performance" in follower stage

5.1.3. Parallel runner stage: involvement and mining of basic generic technology

Incipience (strategy and capability requirements): With the continuous promotion of "replacing steel with plastic" and "replacing wood with plastic", and the consumers' appeal for environmental protection, low carbon and health, the trend of modification technology diversification, high performance of engineering plastics and engineering of general plastics was getting obvious. Meanwhile: in order to keep pace with the development of lightweight of automobile and 5G, the development of high-end modified plastics is imperative. Kingfa put forward the strategic goal of "becoming the world's most excellent material enterprise with high respect in the industry" in 2012. Since then, the technology development goal of Kingfa has changed from creative imitation to independent innovation.

Imbalance (problems and cross-boundary searching): Kingfa found that its existing products and technologies still cannot meet the market demand in a good way, so it needs to carry out deeper R&D and breakthrough on the existing basis to further meet new requirements and challenges. With the continuous accumulation of technological knowledge and enhancement of technological capabilities, Kingfa has been able to step in the high-tech field for new technologies and products such as nanomaterials and carbon fiber. However, the basic and systematic generic technologies are more complicated than applied generic technologies. For example, as a new scientific field, the nanomaterials require the knowledge in biology, physics, materials, chemistry and so on, as well as the integrated research and development by multiple strengths. Meanwhile, since it already represented the highest level of domestic industry, such knowledge was hard to obtain from other partners in the industry. To this end, Kingfa mainly develops basic generic technologies through cooperation with top universities and research institutes at home and abroad, such as the academician workstation.

Cooperation (mode selection and path): Kingfa continuously cooperated with universities and research institutions at home and abroad to establish scientific and technological information platforms, so as to keep abreast of the latest dynamics in polymer research and realize cooperative innovation in fundamental research through various modes, for example, co-building research bases, that is, to build collaborative capabilities in basic research. In fact, Kingfa is cultivating its own basic generic technological capability by constantly cooperating with domestic and foreign universities and scientific research institutions and establishing R&D bases, so as to better explore the basic generic technology. At that time, university-industry collaboration became an auxiliary tool for the technological innovation of enterprises. For an enterprise, the purpose of the university-industry collaboration is to absorb heterogeneous knowledge resources and know the forward-looking basic knowledge.

Results (capability and performance improvement): Upon the development in this period, Kingfa has made remarkable progress in applied researches concerning special engineering plastics, degradable plastics, wood-plastic composites, carbon fiber and its composite materials. Furthermore, it has developed a batch of technologically advanced products with excellent performance, and applied them in high-speed rail, high-end equipment, modern agriculture, building decoration and other industries, which further expands the application fields. The Company cooperated with Sun Yat-sen University and Beijing Technology and Business University for the industrialization technology of PBSA series products in 2014, worked with Sun Yat-sen University and Guangdong Kingfa to break through the key technology of bio-safety disposal and high-value utilization of waste TV shell in 2016, cooperated with Shanghai University, South China University of Technology, Sun Yat-sen University, Guangdong University of Technology and Shenzhen Aerospace Science and Technology Innovation Research Institute on the molding grade applied technology of carbon fiber reinforced high-performance thermoplastic polymer composites in 2019, and cooperated with universities and enterprises, such as HKUST Fok Ying Tung Research Institute, South China University of Technology, Huazhong University of Science and Technology and Nanjing Tech University, to conduct the joint research on the key national research and development tasks of intelligent decision-making, management and control technologies of the mixed manufacturing production line of polymer products in 2020. In regard to the platform capability improvement, it jointly established the "Forward-looking Joint Innovation Center" with GAC Automotive Engineering Institute

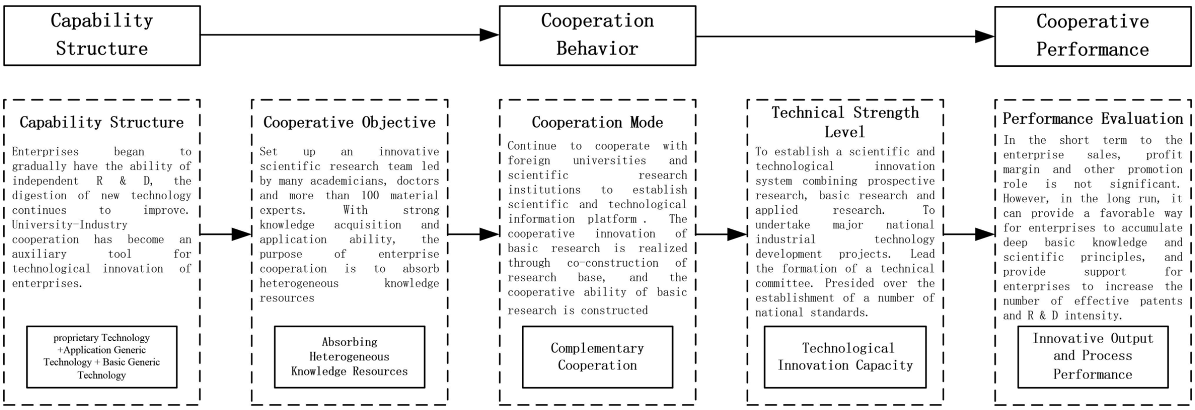

Fig. 4 Effect path of "structure – cooperation - performance" in parallel runner stage

in 2018, and signed a cooperation agreement with Juhua Group for the establishment of a joint laboratory in 2017. In 2013, it successfully passed the acceptance of the construction project "National Engineering Laboratory for Plastic Modification and Processing". Speaking of technological accumulation, a total of 2,983 invention patents have been applied at home and abroad (Figure 4).

5.1.4. Case summary and extraction

In the imitator stage, the enterprise, though having certain product technology, is eager to acquire the ability to produce and commercialize the products with such technology. At this time, companies prefer to choose auxiliary university-industry collaboration methods to optimize their own capability structure. Among them, auxiliary university-industry collaboration refers to the fact that production and integration are consistent with the current technical fields of the company, which can increase the redundancy of corporate knowledge and improve the type of university-industry collaboration based on the knowledge of enterprise professional competitiveness (Zhan *et al.*, 2015). In the actual cooperation process, the main role of the academic and research party is to provide the corresponding proprietary technology or provide related technical consulting services for the company, that is, to solve the problem of the shortage of resources and the inability to develop proprietary technologies due to the shortage of resources. Most of the university-industry collaboration models are technology transfer and commissioned development. Since cooperation is more of a problem-solving short-term project, although the company's proprietary technological capabilities and profitability have been improved, the number of effective patents and R&D intensity of Kingfa during this period are less affected, and the proportion of R&D personnel is moderately improved but still insufficient.

In the follower stage, the enterprise has begun to take shape. It has possessed strong professional technology and some applied generic technological capabilities, and even taken a leading position in the existing technology field, thus, accumulating sufficient capital and resources. In order to realize the leap from proprietary technology to applied generic technology and expand the technical field, the enterprise, based on the existing technological advantages, used auxiliary university-industry collaboration to deepen their original technical capabilities, so as to reduce the risks and uncertainty caused by investment in new technical fields. At the same time, for the purpose of filling up the gaps in internal knowledge types, complementary university-industry collaboration will be adopted to broaden its knowledge breadth and enhance our ability to apply common technologies. The complementary university-industry collaboration refers to the type of collaboration that can reduce the redundancy of enterprise knowledge and improve the knowledge of the enterprise's differentiated competitiveness, which is not available in the production and integration enterprises themselves. Thanks to university-industry collaboration, the depth of technical knowledge of the enterprises has been extended, the R&D intensity, R&D personnel and the number of effective patents has been greatly improved. The breadth of technical knowledge has been broadened, and a significant improvement has been made in the number of R&D personnel in different fields, the number of new products, the sales revenue of new products, and the growth in profit margins. The core competitiveness and organizational learning capabilities of the company itself have also been further improved.

At the stage of parallel runners, with the different enhancement and improvement of enterprise applied generic technological capabilities, the enterprise has gradually begun to own independent research and development capabilities. Therefore, their ability to digest new technologies has been continuously enhanced. University-industry collaboration has become an auxiliary tool for enterprise technological innovation. The major purpose is to absorb heterogeneous knowledge resources, and the intensity of complementary university-industry collaboration will be higher than that of auxiliary university-industry collaboration. The nature and characteristics of the basic generic technology determine that the basic generic technology requires in-depth exploratory learning activities, which mainly solve the novelty and architectural problems of technical principles. The cost and risk of research and development of basic technologies by enterprises alone are extremely high. Therefore, a more feasible way is to take the complementary university-industry collaboration model as the mainstay, which means to attach importance to the research and development of advanced industrial technologies, cross-field technologies, and support and promote the realization of industrial upgrading and independent innovation. It is embodied in cooperation model including the internal integration and co-build R&D entities. Since the complementary university-industry collaboration is mainly engaged in the exploration and in-depth mining of high-tech theoretical innovation and application, it will not have a significant role in promoting enterprise sales and profit margins in short term. However, in long run, it can provide a favorable channel for enterprises to accumulate in-depth basic knowledge and scientific principles, and provide good support for enterprises to enhance basic generic technological capabilities, increase the number of effective patents, increase the number of new products, and the intensity of research and development (Figure 5).

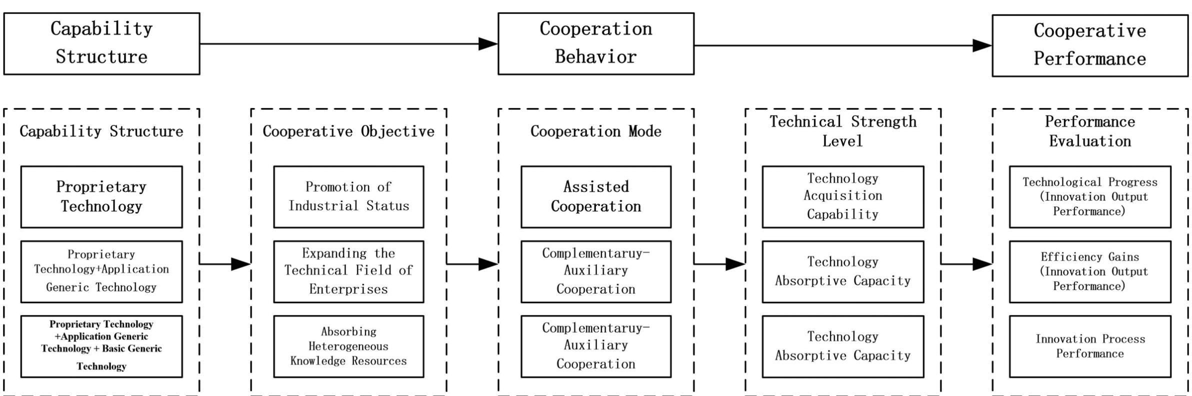

Fig. 5 The interaction mechanism between university-industry collaboration and the improvement of enterprise technological capabilities based on different development stages

5.2 Spiral dynamic evolution trajectory of university-industry collaboration and technological capability improvement

5.2.1. The evolution process of enterprise technological capabilities structure

At the beginning of entrepreneurship, Kingfa did not form a true organizational ability, but only had certain product technologies. At that time, Kingfa focused on survival, solving product technology and production problems through university-industry collaboration, and establishing terminal product production capabilities based on the original technology. After growing to a certain scale of production, the enterprise has entered the growth stage, through the transformation and application of industrial technology through cooperation with university projects, developing more new products, and thus establishing a cooperative R&D center for the development of alternative industrial technologies. At the same time, by cooperating with industry chain partners, the enterprise has obtained supply and demand information to further expand its knowledge acquisition and application capabilities, and the application of generic technologies could be rapidly improved. In the mature stage, Kingfa has reached the international advanced level in R&D and production capabilities in HIPS and PP materials, which fully presents the characteristics of core capabilities including user value and difficulty in imitating, but at this time the competitive advantage is still relatively single. In order to meet market demand in a timely manner and obtain a diversified competitive advantage, it optimizes and integrates the basic knowledge of the academic and research party, the industrial knowledge of upstream and downstream enterprises, and the funding provided by the government through the industrial technology alliance model. It also needs to integrate multi-domain knowledge to develop and apply new-generation industrial technologies such as bio-nanotechnology (PBSA), combine core capabilities with the development of cutting-edge science and technology, thus greatly improving basic generic technological capabilities, and building dynamic capabilities that can quickly adapt to the external environment.

5.2.2. The co-evolving trajectory of enterprise technological capability structure and the university-industry collaboration model

For example, at the beginning of its establishment, Kingfa accomplished the leap from patented technology to product realization through the auxiliary university-industry collaboration with Sun Yat-sen University, and gained economic benefits. After realizing the production and sales of flame retardant HIPS, its managers found that only mastering one kind of proprietary technology could not enable the company to gain a sustainable competitive advantage. To this end, Kingfa has developed new products by using the industrial technology transformation and application through project cooperation with universities, and established a cooperative R&D center for new industrial technology development. While cooperating with academic research institutions to improve generic technical capabilities, Kingfa also pays attention to establishing strategic alliances with industrial chain partners, obtaining supply and demand information through industrial chain cooperation, expanding production lines by purchasing advanced equipment, and further expanding production scale. These measures have laid the foundation for product line expansion beyond the "Familiar Trap1". Currently, modified plastic technology has leapfrogged to the field of biotechnology. Cross-field technology research and development not only requires huge investment, but also the cooperation of different partners. Therefore, Kingfa develops and applies new bio-nanotechnology and other industrial upgrading technologies through the integration of multi-domain knowledge, and combines core capabilities with

[1] Familiar trap: lay too much emphasis on the application and improvement of existing knowledge, while ignoring the exploration of alternative knowledge

[2] Approaching trap: enterprises only focus on the development of existing fields, ignoring the overall technological changes in the industry

Table 3 Development history of Kingfa

Stages	Startup Stage	Growth Stage		Maturity Stage
Year	1993-1997	1998-2002	2003-2012	2013-
Main Technological Goals	HIPS Product Production Technology	Improved Technology of HIPS and PP Technology	PBSA and Other New-Generation Industrial Technology Innovation	Research and development of high-end new materials, formulation of industrial technical standards
Important Events	Interact with university research personnel; establish a production line to produce and sell flame-retardant HIPS	Establish an independent innovation strategy; establish post-doctoral workstations; introduce advanced know-how and equipment; establish university-industry research and supply chain cooperation; expand production size and increase product categories	Establish academician workstations; boost R&D investment; jointly build up R&D laboratories and engineering laboratories; conduct mergers and acquisitions to establish PBSA technology R&D and commercialization base	A scientific and technological innovation system that combines forward-looking research, basic research and applied research; undertakes major national industrial technology development projects; takes the lead in the establishment of technical committees and presided over the formulation of a number of national standards
Capability Improvement	Proprietary technology (cultivating technology transformation and application capabilities around the technical foundation already possessed)	Proprietary technology + applied generic technology exploration (improving existing industrial application technology, developing technology applications, and cultivating time-oriented technical capabilities)	Proprietary technology + applied generic technology application (formed a complementary integration of multiple technologies)	Proprietary technology + applied generic technology + basic generic technology exploration (based on external technology and demand changes, update core capabilities to cultivate multi-level competitive advantages)

the development of cutting-edge science and technology, which has greatly enhanced the update and transformation of core capabilities, thereby avoiding possible “Approaching Trap2”, so that enterprise always maintains a competitive advantage (Table 3).

5.2.3. The co-evolution trajectory of enterprise technological capabilities structure, university-industry collaboration model and cooperation performance

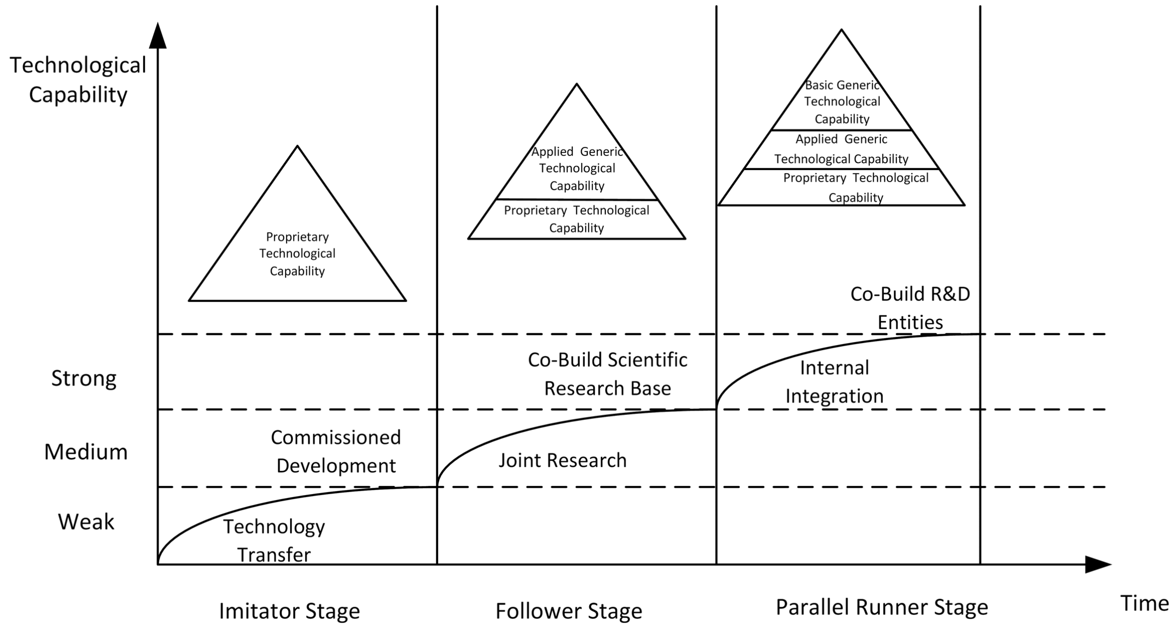

Fig. 6 The co-evolution process of the dynamic capabilities of university-industry research and cooperation model

The evolution of technological capabilities of an enterprise is a process of accumulation of static quantities into dynamic qualitative changes (Figure 6). It is the process of technological increment (new knowledge, new technology) activating the technological stock (the sum of resources contained in the four elements of personnel, equipment, organization and information). In the stage of imitators, Kingfa's personnel, equipment, and other elements have no advantages, and the technology stock is low. It can only rely on university-industry collaboration to help improve its own deficiencies in new knowledge and new technologies. Through the process of technology productization, it can achieve profit goals and enhancement of proprietary technological capability. Since 1995, it has introduced high-tech talents and has its first production equipment. Organizational performance and R&D level have been also rapidly improved. With a certain level of proprietary technology and profitability, Kingfa has begun to have the conditions to explore and mine applied generic technologies. To truly master and possess generic technologies, however, it also needs to have a number of basic conditions, including being equipped with a talent team with senior technical titles and doctoral degrees, advanced and sufficient production equipment, and the establishment of a technology center and other R&D and innovation platforms. Therefore, in the follower stage, Kingfa began to expand from the household appliance industry to the automotive industry, and began to focus and embark on the technological development of the upstream of the industrial chain. In 2002, it established a technology center to continuously cultivate talents and build an innovation platform, while paying attention to and emphasizing the continuity of university-industry collaboration. In 2006, it began to engage in technical excavation and in-depth development of special engineering plastics and degradable plastics. During the period, university-industry collaboration has shifted from a short-term cooperation focusing on product improvement to a continuous university-industry collaboration model focusing on technology development, improvement and applied research. In 2012, Kingfa has a professional scientific research team composed of 4 outstanding experts receiving State Council Special Allowance, more than 100 doctoral-degree holders and more than 400 master-degree holders, and an expert consulting team composed of 12 academicians and 35 senior experts at home and abroad. The technological development instruments and equipment it possesses are even more advanced than those of the Polymer Materials Research Institute of Sichuan University, which is the highest level among domestic research institutes. By taking the lead in the establishment of an industry alliance innovation network, Kingfa Technology's industrial chain layout capabilities have been greatly improved, which facilitates timely understanding of the industry's forward-looking knowledge, information and technological trends.

In the stage of parallel runners, Kingfa has established an independent innovation system with a nationally recognized enterprise technology center as the core, and further established and improved the national engineering laboratory for plastic modification and processing, UL-approved LTTA CTDP laboratory, post-doctoral research workstation, Guangdong Provincial Special Engineering Plastics Key Laboratory and other domestic first-class scientific research and development platforms. It has implemented major projects such as key technologies for the industrialization of special engineering plastics including high temperature resistant nylon and polyether ether ketone, further enhancing the ability to develop generic technologies. In order to achieve the strategic goal of running forward from a follower to a leader, Kingfa emphasizes the principle of "Both fields shall be developed and mastered" in applied research and forward-looking research. With strengthening the enterprise's close university-industry collaboration with domestic and foreign universities and research institutes, the enterprise's independent innovation capabilities have been enhanced. Up to now, the Kingfa has been equipped with a scientific research team consists of 15 academician-level expert consultants, more than 100 senior experts at home and abroad, and 132 doctors. It has independently nurtured 5 experts with special allowance from the State Council and 69 senior engineers. It has established a scientific and technological innovation

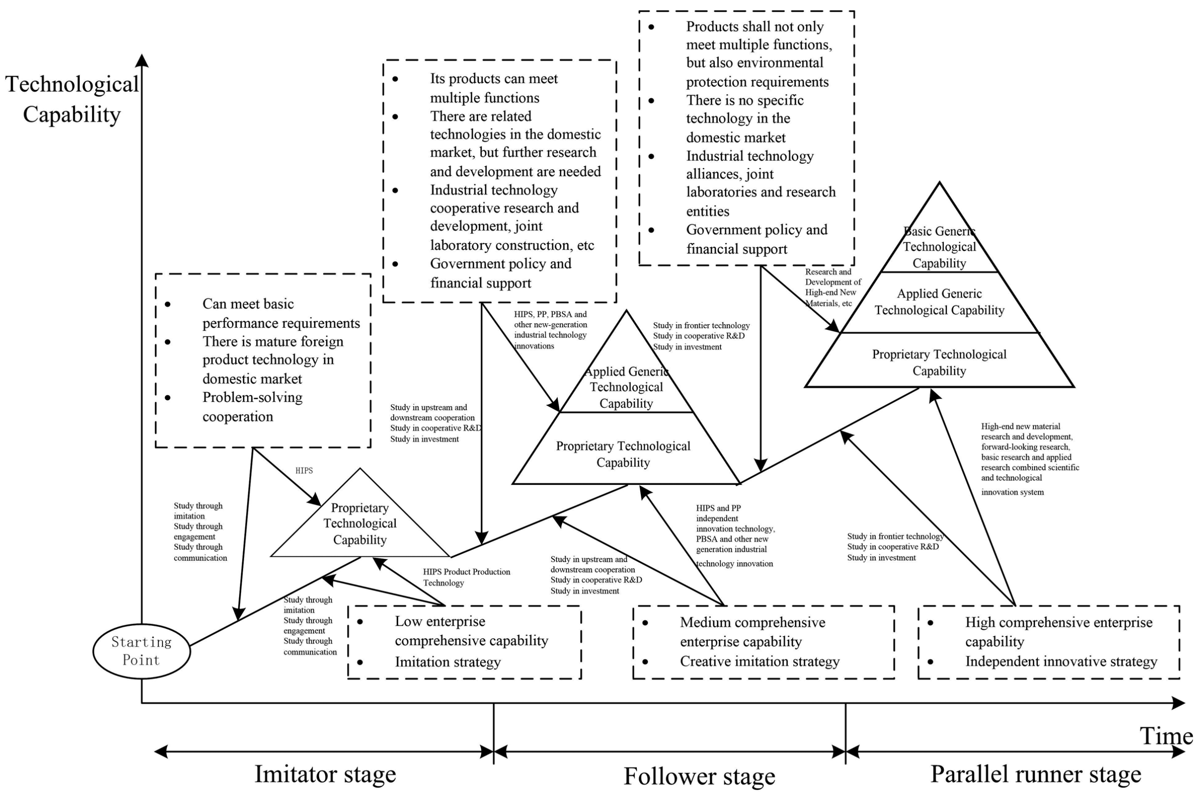

Fig. 7 Evolution of Kingfa's technological capability structure

system that combines forward-looking research, basic research and applied research, and has undertaken more than 40 national and provincial key scientific research projects such as national key research and development tasks, "863 Program" and "Science Support Program". It has led the establishment of the "National Plastics Standards Committee Modified Plastics Subcommittee", presided over the formulation of 25 national standards, participated in the formulation and revision of more than 90 national and industry standards, and seized the commanding heights of industrial development. The above-mentioned results provide support for talents, technology and innovation system for the follow-up improvement of Kingfa's technological capabilities (Figure 7).

5.2.4. Case summary and extraction

From the perspective of overall dynamic development in the long run, at different periods of development, enterprises will have differentiated capability requirements and cooperation motivations based on different strategic goals and capability levels, and corresponding university-industry collaboration goals and models will also change. In the initial stage of university-industry collaboration, the production capacity and R&D capabilities of enterprises are weak, and they need to rely on university-industry collaboration to achieve technological innovation. Enterprises tend to adopt the mode of auxiliary university-industry collaboration, obtain more mature proprietary technology, and play an important role in optimizing the existing production process, improving the current product technology, and enhancing the overall capabilities of the enterprise. After entering the growth period, the learning and imitation capabilities of enterprises have been significantly improved. The focus of university-industry collaboration is on the development of applied generic technologies. Enterprises have begun to gradually increase the intensity of complementary university-industry collaboration, and will also add a certain degree of auxiliary university-industry collaboration to digest and absorb newly introduced technological resources. After stepping into the mature period, the independent research and development capabilities

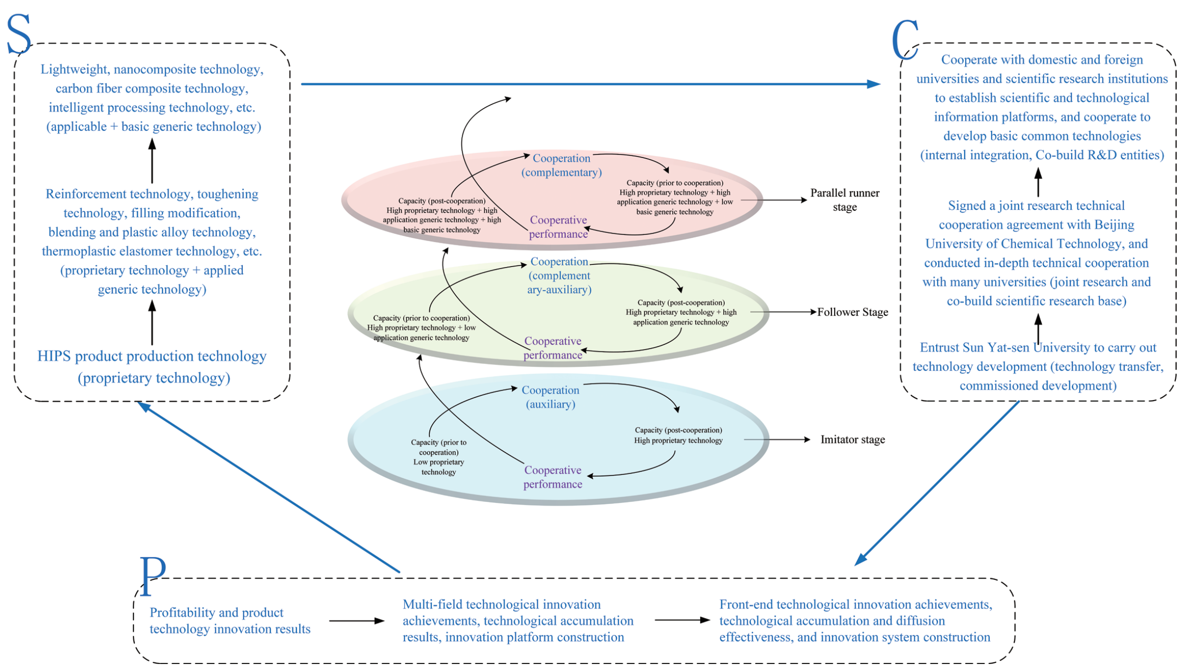

Fig. 8 The spiral dynamic evolution trajectory of university-industry collaboration to the improvement of enterprise technological capabilities

of enterprises continue to improve, and university-industry collaboration has become an auxiliary tool for enterprise technological innovation. At this time, the level of technical cooperation is concentrated on the field of basic technology, focusing on the introduction of complementary technologies. Since the complementary university-industry collaboration is mainly engaged in the exploration and in-depth mining of high-tech theoretical innovation and application, it will not have a significant role in promoting enterprise sales and profit margins in short term. However, to enhance the basic generic technological capability for enterprises is more beneficial for enterprises to avoid falling into the "Capacity Trap", break through the constraints of limited resources, and enhance their own innovation ability to adapt to environmental changes.

Therefore, looking at the entire development process of an enterprise, the dynamic evolution process of enterprise technological capabilities has experienced from proprietary technological capabilities to the coexistence of proprietary technological capability, and applied generic technological capability, and finally the process of coexistence with proprietary technological capability, applied generic technological capability and basic generic technological capability. The model of cooperation has also undergone correspondingly from the auxiliary cooperation model (technology transfer, commissioned development) of production problem solving to the complementary auxiliary mode (joint research, co-build scientific research base), and then to the complementary mode (internal integration, co-build R&D entities) evolution. The leap and improvement of capabilities and cooperation models between different periods will bring about technological progress, benefit enhancement, and improvement of the performance of the innovation process, which will provide technical support and resource foundation for the next stage of capability enhancement. This series of evolutionary trajectories is not a simple arrangement in time series, but presents a spiraling development path, reflecting the co-evolution process of the enterprise technological capabilities structure and the mode of university-industry collaboration with the improvement of enterprise performance (Figure 8).

6. Management Enlightenment and Policy Recommendations

6.1. Management enlightenment

The weakness of applied generic technological capability is the root cause of the hollowing out of the core technology of our country's industry, as well as the weak independent innovation and absorptive capacity of enterprises. Based on the current dilemma in the improvement of enterprise technology capabilities, this paper starts from the perspective of the innovation capability structure of the main body of university-industry collaboration, based on the SCP theory of university-industry collaboration innovation, and discusses the interactive mechanism of university-industry collaboration on the improvement of enterprise technology capabilities under the Chinese scenario. It expects to provide a feasible development path for Chinese enterprises to improve their generic technological capability.

Specifically, the management enlightenment of this paper is mainly manifested in three aspects:

First, enterprises should review and clarify the level and structure of their own technological capabilities, and choose different capability improvement paths for different structures and capabilities requirements. The evolutionary law of the technological capability structure has undergone from proprietary technological capability to the coexistence of proprietary technological capability and applied generic technological capability, and finally the process of coexistence of proprietary technological capability, applied generic technological capability and basic generic technological capability. The above-mentioned structure and characteristics well demonstrate the characteristics of Chinese enterprises in the technological reverse path, and also verify the close connection between enterprise technological capabilities and cooperative innovation.

Second, enterprises should pay attention to the compatibility of university-industry collaboration models and capacity enhancement based on their own technological capabilities and development positioning. For example, enterprises wishing to upgrade their proprietary technologies shall aim to promote gradual improvements in design, manufacturing, and research and development, etc., with production, education and research focusing on short-term technology transfer and commissioned research and development. Enterprises aiming to upgrade from proprietary technologies to applied generic technologies need to develop functional and serialized products and conquer industry technologies. Therefore, they need to rely on scientific research institutions to provide cross-technology knowledge to make up for their own technological gaps. And enterprises hoping to improve basic generic technologies need university-industry collaboration to increase their own scientific knowledge and cutting-edge knowledge accumulation, which is mostly manifested in long-term-oriented cooperation, such as internal integration and co-build R&D entities.

Third, applied generic technology is the integral part to the formation and transformation of enterprises' independent innovation capabilities. Based on China's real condition, the current focus of university-industry collaboration is more reflected in the satisfaction of product development needs, and collaboration is more mirrored in two-to-two "technology transactions", ignoring effective support for generic technology research and development and transformation, leading to low efficiency of independent innovation capability of enterprises. Among generic technology, applied generic technology plays a connecting role in the process of transforming basic knowledge to productivity, and is also the basis for enterprise research and development and exclusive core product technology. For the long-term development, only by enhancing the R&D and transformation activities of their own applied generic technologies can they build and improve their own R&D and manufacturing capabilities and finally win sustainable competitiveness.

6.2. Policy recommendations

University-industry collaboration is an effective and critical measure to improve the common technical capabilities of enterprises. However, as generic technologies have the attributes of "pre-competitive" quasi-public goods, they usually face the problem of "market failure" where R&D subjects are absent and inputs are different, and require policy support and assistance from the national government. The Chinese government has always been attaching importance to the development of generic technology and has provided long-term investment support for generic technology innovations, such as the 13th Five-Year National Science and Technology Innovation Plan and Industry Key Generic Technology Development Guidelines (2017) issued in recent years clearly take the innovation of generic technology as the focus of support. However, the practice from the 1992 "University-Industry Collaboration Joint Development Project" to the "Industrial Technology Strategic Alliance" has shown that government's intervention in the collaborative innovation of university-industry collaboration institutions is a failure phenomenon. At the same time, there are also some improvement room in terms of overall policy layout and design. Therefore, the design of the future university-industry collaborative innovation policy must overcome the imperfect policies to maximize the collaborative innovation force. Based on this, this paper proposes the following policy recommendations:

Firstly, the enterprise's innovation capacity building and the recognition of the dominant position shall be further strengthened to establish a multi-level university-industry collaboration system. First of all, policy design and guidance need to stress the main role and leading role of enterprises in innovation. Second, according to the endogenous needs of enterprises for technology at different stages of technological innovation, enterprises shall be encouraged to engage in innovative cooperation with domestic universities, scientific research institutes, and overseas technologically advanced enterprises. Moreover, it is also necessary to underscore the guiding role of the market in the direction of technology research and development, route selection, factor prices, and allocation of various innovative factors. When facing the needs of basic generic technology and applied generic technology of enterprises, the government could vigorously develop new R&D institutions, university scientific research bases, industrial technology alliances and other forms to integrate superior science and technology resources to lay out the innovation chain and provide overall solutions with industrial technological innovation to solve the problem of insufficient capabilities of individual enterprises in the process of generic technology development. Finally, the development of competitive new technologies, new products, and new formats should be decided by the market and enterprises. The government mainly takes advantages of the creation of an innovative system environment and an intellectual property environment, as well as the improvement of related supporting laws and regulations, to play a role as a supervisor and regulator.

Secondly, new systems and mechanisms for the construction of high-end frontier R&D institutions shall be actively explored with the involvement of enterprises and universities. On the one hand, endeavors shall be made to continue to increase the investment of financial funds, promote the integration of university basic research and industrial development, and give full play to the university's "fusion" effect of innovation in many aspects such as the training of scientific and technological talents, technological innovation, sustainable economic development and cultural construction. And on the other hand, premium shall be put on the introduction and development of a number of well-known universities and key disciplines at home and abroad, and make docking between industry chains and discipline clusters and between industrial clusters and discipline chains to solve the shortcomings of insufficient scientific and technological resources, thereby maximizing independent innovation capabilities. Finally, open operating mechanism of scientific research bases and innovation and entrepreneurship platforms shall be strengthened to encourage and support large-scale leading enterprises or high-tech enterprises in accordance with their long-term development plans and market competition laws, to participate in the discipline construction of universities in a targeted manner, and facilitate the construction of a dynamic discipline system with distinctive features and cross-integration of universities, and promote the effective improvement of enterprises' new product development and technological innovation capabilities.

Thirdly, comprehensive reform of the science and technology management system in terms of the market, finance, and entrepreneurial environment shall be advanced. First, in terms of the market environment, it is necessary to continuously improve market rules, regulate market order and improve intellectual property laws and regulations. It also needs to implement intellectual property rights protection measures, promote the creation, protection, management and use of intellectual property rights, and provide guarantee and confidence for innovation. Second, in terms of the financial environment, promote the deep integration of technology and finance. Government financial resources should give full play to their leading role, focus on the effective balance between policy and commercial technology and finance, and concentrate on how to make the government's guiding role while not undermine the market's decisive role in resource allocation. Besides, it is also necessary to improve the Internet equity crowdfunding financing mechanism, develop a regional equity trading market, continuously improve the financial support mechanism for innovation and entrepreneurship, and strive to build a multi-level technology financial service system. Finally, efforts shall be invested to improve the business environment and provided fertile soil for university-industry collaboration and technological capacity improvement. First, build up a platform for innovation and entrepreneurship, vigorously develop mass innovation, crowd-sourcing, crowd-supporting and crowdfunding, and facilitate the construction of mass innovation platform that is convenient and accessible. Second, implement an innovative administrative approval mechanism to serve entrepreneurs. Third, focus on the entrepreneurial incubation system, improve the entrepreneurship training and guidance, and enhance the entrepreneurial willingness and ability.

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