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Research Paper

A Study of Methods to Identify Industry-University-Research Institution Cooperation Partners based on Innovation Chain Theory

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Abstract

Purpose: This study aims at identifying potential industry-university-research collaboration (IURC) partners effectively and analyzes the conditions and dynamics in the IURC process based on innovation chain theory.

Design/methodology/approach: The method utilizes multisource data, combining bibliometric and econometrics analyses to capture the core network of the existing collaboration networks and institution competitiveness in the innovation chain. Furthermore, a new identification method is constructed that takes into account the law of scientific research cooperation and economic factors.

Findings: Empirical analysis of the genetic engineering vaccine field shows that through the distribution characteristics of creative technologies from different institutions, the analysis based on the innovation chain can identify the more complementary capacities among organizations.

Research limitations: In this study, the overall approach is shaped by the theoretical concept of an innovation chain, a linear innovation model with specific types or stages of innovation activities in each phase of the chain, and may, thus, overlook important feedback mechanisms in the innovation process.

Practical implications: Industry-university-research institution collaborations are extremely important in promoting the dissemination of innovative knowledge, enhancing the quality of innovation products, and facilitating the transformation of scientific achievements.

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Originality/value: Compared to previous studies, this study emulates the real conditions of IURC. Thus, the rule of technological innovation can be better revealed, the potential partners of IURC can be identified more readily, and the conclusion has more value.

Keywords Institutions collaboration; Collaboration network; Innovation chain; Industrial chain; Industry-university-research institutions

1 Introduction

At present, the research and development (R&D) capabilities of Chinese enterprises are generally weak and the conversion rate for scientific achievements at research institutes and universities is relatively low (Shen, 2016). The reason technology transfer does not go smoothly is that there are obstacles to the diffusion of innovation elements in the innovation chain. It has been proven that cooperation across industry, universities, and research institutions is one way to effectively promote the diffusion of such innovation elements in the innovation chain (Huang et al., 2017). Thus, the requirement for enhancing such industry-university-research institution collaboration (IURC) is particularly urgent. Accordingly, identifying the potential IURC partnership is critical for promoting the conversion and implementation of scientific achievements in China. Most existing methods for identifying such cooperative partners are based on technology similarities in institutional R&D. However, the IURC cluster, represented by the industrial cluster in China, has not achieved collaboration innovation. One major reason is the fierce competition that stems from extreme homogenization, making it difficult to generate a cluster effect and achieve collaboration effectively (Huang, 2014). Therefore, methods that are solely based on technical similarities are not necessarily effective in identifying IURC partners.

The method proposed in this paper is meant to improve the matching process for collaborative partners, and thereby, overcome barriers in the innovation process that prevent collaborations from forming and to encourage innovations to move along the chain. In this study, we apply innovation chain theory, considering knowledge spillover effects in the innovation chain and important variables that affect IURC. We begin with the law of innovation dissemination, utilizing multisource data and combining bibliometric and econometrics analyses to identify IURC partners.

2 The status quo of IURC partner identification

2.1 The status quo of the quantitative analysis method in IURC partner identification

Yoon and Song (2014) summarized the methods for partner selection and classified them into three categories: mathematical programming approaches (Soles-vik &

Encheva 2010), rating/linear weighting approaches (Wang & Chen 2007), and artificial intelligence techniques (Fischer, Jähn, & Teich, 2004). They utilized patent information to investigate innovation activities by applying morphological analyses (MA) and generative topology maps (GTM) to the process used in identifying technology configurations and visualizing the collected patent information. Park et al. (2015) explored potential R&D collaboration partners through patent analysis based on bibliographic coupling and latent semantic analyses. The potential R&D collaboration partners were visualized in the form of a patent-assignee-level map based on the technological similarity between patents using network analyses. Wang et al. (2017) identified R&D partners through subject-action-object (SAO) semantic analyses in a problem and solution pattern and combination term clumping. Xu et al. (2015, 2016) used multiple indicators to synthetically assess the new IURC situation and identify cooperation partners for collaboration. By extending a multimodal data analysis and by considering the technical similarity of IURC institutions, the competitive position, types, and core-periphery structures of these institutions in the cooperation network, potential IURC partners were identified.

Most existing studies on IURC employ a single variable to identify cooperation partners. Such studies still lack comprehensiveness in cooperative partner identification and consider the technology similarity only from a technical point of view. Even if one begins with technology similarity to identify some potential IURC possibilities, it is inappropriate to identify IURC partners using only technical similarity. For example, the IURC cluster—represented by the industrial cluster in China—has not achieved collaboration innovation. The reasons for this are that the degree of industry specialization within the cluster chain is still rather low and fierce competition caused by homogenization make it difficult to achieve collaboration effectively (Huang, 2014). Thus, the similarity of the technology, but not its convergence, is an important factor in cluster innovation and proper IURC. Therefore, it is necessary for institutions to identify proper IURC partners with more complementary capabilities.

2.2 The forming condition of knowledge spillover effect in IURC

There are significant differences between IURC and pure scientific research cooperation. When a sustainable IURC partnership is formed, it needs to consider several market factors beyond research ability from industrial and economic perspectives. When the rules and characteristics of cooperation are known, the IURC can be established. Therefore, only when the factors of collaboration have been recognized, can potential IURC partners be identified effectively. Usually, both cooperation and competition exist at the same time where similar technologies exist.

However, for IURC, it is only when cooperation is heavily emphasized that knowledge spillover effects occur.

In an IURC that works well, the expectation from universities and research institutions is to bring their scientific innovations and inventions to market, thereby promoting economic development, and gaining further financial support for R&D (Xu et al., 2017). On the other hand, industry enterprises expect to gain more advanced technology to upgrade their products. Furthermore, some disruptive innovation can possibly generate more competitive advantages and higher profits (Zhang, 2012). The promotion of and demand for scientific innovation in universities, research institutes, and industries are referred to as “knowledge potential.” The essence of knowledge potential is the “push” and “pull” effect in knowledge dissemination. This knowledge potential is then the innovation impetus in the formation of the IURC (Yue et al., 2015).

3 Methodology of IURC partners based on innovation chain theory

3.1 The connotation of innovation chain theory and its applicability in IURC

Cai (2002) defined the innovation chain theory as the commercialized process of science and technology knowledge through the transformation of technical innovation (Cai et al., 2001). The thinking around the innovation chain optimizes the innovation process through systematic analysis. The driving force behind the innovation chain largely comes from demand; it is a functionally linked network structure model that is demand-driven. The functional links are node links that can meet some specific functions (Bamfield, 2006; Larson & Brahmakulam, 2002; Liang, 2007; Timmers, 1999). In this study, the innovation chain is defined as a chain process with five orderly innovation goals: the transformation of scientific problems to scientific theory, the transformation of scientific theory to practical application, the transformation of actual application to product manufacturing, the transformation of product manufacturing to commodities, and the transformation of goods to industrialized production.

Given that the essence of the innovation chain is the dissemination of innovation factors consistent with the IURC process that leads to the knowledge spillover effect, innovation chain theory can effectively describe the characteristics of knowledge spillover and exchange phenomena in IURC. Accordingly, this paper presents a new method to identify IURC partners based on innovation chain theory, attempting to survey the distribution of innovation technology in the innovation chain of different institutions in search of additional complementary capabilities among them.

3.2 Model of the innovation chain

According to the different goals of innovative activities in the innovation chain, we divide the chain into five phases: basic research, application research, transfer and transformation, commercialization, and industrialization (Figure 1). The different innovation phases have specific innovation activities but are connected to each other and work synergistically. Each innovation phase is divided into several functional nodes including enterprises, scientific research institutions (research institutes and universities), government-involved innovative activities, and other innovation elements. The innovation is driven by the interaction between these functional nodes.

The reason technology transfer does not go smoothly is that there are obstacles to the diffusion of innovation elements in the innovation chain. IURC is one way to effectively promote the diffusion of innovation elements in the innovation chain.

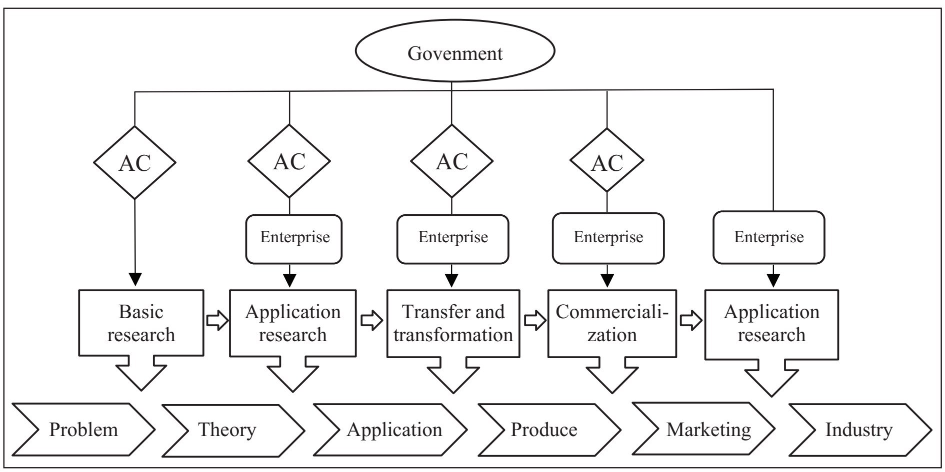

Figure 1. Model of the innovation chain

In this study, IURC identification research is established based on the entire innovation process, including a series of orderly innovation targets. The detailed analysis is as follows:

(1) In the basic research phase, scientific problems are formulated into scientific theories. The evaluation index in this phase is a comparative analysis of quantity and quality based on scientific research papers.
(2) In the application research phase, scientific theory is further transformed into a practical application. The evaluation index in this phase is a comparative analysis of quantity and quality based on patent applications and authorizations.

Both the basic and application phases are part of technology development activity and universities and research institutes are the most important participants, although a few research enterprises with strong R&D divisions also conduct some basic and applied research in China.

(3) In the transfer and transformation phases, enterprises begin to participate as scientific research institutions. The evaluation index in this phase is the number of technologies transformed into technological achievements.
(4) In the commercialization phase, products are developed for sale in the market. The evaluation index is the quantity of the commodities.
(5) The target of the industrialization phase is to achieve industrialization, and the evaluation index is the industrial scale.

The commercialization and industrialization phases are part of the economic activity category, and enterprises are the major participants, while universities and research institutes are also participants.

3.3 Identification method of IURC partners

The process of IURC partner identification based on innovation chain theory is divided into two modules: (1) core network analysis of the existing cooperative institutions, and (2) institutional competitiveness analysis based on the innovation chain.

(1) The core network analysis of the existing institutions

The cooperative network is a complex one. In the cooperative network, although the number of nodes is very large, its core nodes are very small. From the structural viewpoint of the complex network, these core nodes are connected closely, while other noncore nodes are connected to these core nodes only by a few edges.

The core nodes of a complex network can be found through the k-core network. For a network, if any node has at least k neighbors that are also in the same network, then the network is a k-core network (Baxter et al., 2012; Newman, 2003). K-core nodes are the core nodes in a complex network and k-core analysis is often used to mine core members. In this study, the k-core network is used to analyze the core cooperative institutions in the basic and applied research phases.

(2) The institutional competitiveness analysis based on the innovation chain

The institutional competitiveness analysis contains two-levels of evaluation indicators. The first-level indicators are the potential variables: basic research, applied research, transfer and transformation, commercialization, and industrialization. To ensure the integrity and data availability of the evaluation indices, the participants in each phase are considered as the analyzed objects and research papers, patents, industrial, and economic data, as the second-level indicators. The evaluation content is subdivided by the secondary indicators and the comprehensive and accuracy of the institutional competitiveness analysis can be further improved.

According to Table 1, feasible measures are selected to analyze the layout of the innovation chain and institutional competitiveness in the field.

Table 1. Evaluation indexes of institutional competitiveness based on innovation chain.

First-level indexes	Innovation target	Category	Participate subjects	Second-level indexes
Basic research	Problem→Theory	technology	University, R& D institutes	research papers
Application research	Theory→Appliaction	technology	University, R&D institutes	patents
Transfer and Transformation	Appliaction→Production	technology	University, R&D institutes, enterprises	technological achievements amount
Commercialization	Production→Marketing	economic	enterprises	goods amount
Industrialization	Marketing→Industry	economic	Production subject, sales subject	industrial scale

a. Basic research analysis

To access the relationship between the amount of basic research, the influences on the basic research results, and the basic research areas of the core institutions, the research papers in the database of academic resources are identified, and the quantity, influences on these papers, and the relationships between institutions analyzed.

Both the citation analysis and the citation impact analysis index (CNCI) (Incites, 2015) are used to analyze research influence. CNCI is a relative evaluation indicator in the Thomson Reuters InCites™ database. CNCI is an unbiased indicator that excludes the subject area, publication year, and document type. The influence of collected papers of different sizes and different subjects can be compared using the CNCI. When the value of the CNCI is equal to one, the cited performance of this group of papers is equivalent to the global average. Thus, if the index value is greater than one, the cited performance of this group of papers is higher than the global average. Correspondingly, if the index value is less than one, the cited performance is lower than the global average. If CNCI is equal to N (N≥2), the cited papers of this group are N times higher than the global average.

b. Applied research analysis

The patents are retrieved from a patent database and used to analyze their quantitative characteristics to determine the quantity of applied research, the level of the applied research institution in the core research institution network in basic research, and the relationship between core institutions in applied research.

The quantitative patent analysis also includes the analysis of the quantitative characteristics of patents from various patent institutions and different regions. This study uses comparative analyses to assess and compare the basic research papers and quantitative characteristics of the patents in the basic field and to measure the basic and applied research levels at the same institution.

c. The analysis of transfer and transformation, commercialization, and industrialization

The data for the transformation, commercialization, and industrialization of related research institutions are retrieved from government and trade association websites and economic databases. The transfer and transformation analyses focus on the quantitative characteristics of the products that can be produced. The degree of transfer of the applied research is evaluated by comparing the relationship between the applied research results and the quantity of products that can be produced. The main research of the commercialization analysis is in the context of products converted into goods for sale. The extent of commercialization is evaluated by comparing the number of products and the products that can be marketed as well as the quantity associations. The industry scales can be further divided into the objects of production and sales. The degree of industrialization can be evaluated by analyzing the quantity characteristics and geographical distribution of the objects of production and sales.

3.4 The hypothesis of IURC partner identification

Listed below are the four hypotheses that identify the IURC partners based on the innovation chain theory.

***Hypothesis 1*:** There is a greater potential for collaboration among agencies with different attributes of spatial distribution in the innovation chain. Thus, the competition within universities-enterprises or research institutes-enterprises is less than enterprises- enterprises.

This hypothesis stems from the belief that the heterogeneity capacity of different institutions in the innovation chain can contribute to cooperation potential. The primary choice in the selection of the cooperation partner is whether the partner to be selected can provide some advantage or expertise, and whether it can bring in complementary resources to achieve a goal that cannot be achieved by the primary establishment relying on its own resources. Kogut and Chang (1991) pointed out that complementary resources are a key driver in cross-organizational cooperation based on resources. Laursen and Salter (2006) argued that the rapid development of technology makes the business model of the enterprise more open, and technology is more dependent on external sources, especially in the high-tech industry.

Hypothesis 2**:** Institutions facing increased competitiveness have more opportunities in establishing cooperative partnerships. If an institution is in a phase with increased competitiveness for basic research, applied research, transfer and transformation, commercialization, and industrialization, then it is more likely that this institution will be selected as a cooperative partner.

This hypothesis arises from the mechanism of preferential attachment in the collaborators' selection. It has also been shown that competitive factors, such as knowledge capacity and market coverage, are important, and it is more likely that institutions who hold more patents, patent licenses, and trademarks, will be selected as collaborators (Barber, 2007).

Hypothesis 3**:** Institutions that are geographically closer have more opportunities for cooperation. However, a spatial location advantage is not a major influential factor in the development of current prosperous networks.

This hypothesis derives from that the fact that the spatial advantage can reduce the cost of cooperation. Wen (2012) studied a cooperative model of patents systematically with quantitative methods and conducted a quantitative analysis on the cooperative relationship and cooperation mode between inventors and patent holders. She also analyzed the knowledge exchange accompanied by patent cooperation and summed up the laws and patterns of knowledge exchange; she found that the closer the spatial location between institutions, the greater the possibility for patent cooperation between them.

In modern China, local government is most interested in its own regional economic development through the promotion of cooperation between industry and academia in the local region. Therefore, there are still some obstacles in cross-regional cooperation (Qing & Liu, 2016).

Hypothesis 4**:** If an institution is very prominent in the cooperative network, and there are prior cooperation activities, the institution represents an open-type innovation institution with greater potential to cooperate.

This hypothesis derives from the belief that if there are cooperation experiences among institutions, there is increased trust among them, establishing a smoother cooperation outcome (Barber, 2007).

4 Empirical analysis

4.1 Data sources and analysis tools

The gene engineered vaccine (GEV), also known as the "genetically engineered vaccine," is the vaccine produced by recombinant DNA cloning; it is the expression of the protective antigen gene, or produced by the expressed antigen products, or the recombinant itself (Tang et al., 2006). As the vaccine industry is related to strategic security, it has received extensive attention in many countries. Further, the GEV is a typical high technology with an intact knowledge innovation chain. Therefore, this study chose the major research institutions in the field of GEVs to identify potential cooperation partners.

This empirical analysis is based on the SCI papers indexed by the Web of Knowledge and the Derwent innovations index database and retrieved June 2015. We built a detailed search strategy (not shown here owing to its complexity), and obtained 3962 papers and 999 Chinese patent applications. The Thomson Data Analyzer (TDA) (Thomson Reuters, 2015) was used for text data analyses. We then identified major patent holders, technical topics, and types and names of institutions as the basis for the data analysis, ultimately, obtaining a result with 180 institutions.

4.2 The k-core analysis of the existing cooperation institutions network

Figure 2 is the k-core network based on co-authored papers where the number of co-occurrences is no less than three. Figure 2 shows three cooperative networks involving three domestic research institutions including. The first one is Shanghai Jiaotong University, Fudan University, the Chinese Academy of Sciences. The second one is Chinese Academy of Military Medical Sciences and Chinese Academy of Agricultural Sciences. The third one is Academy of Medical Sciences (Peking

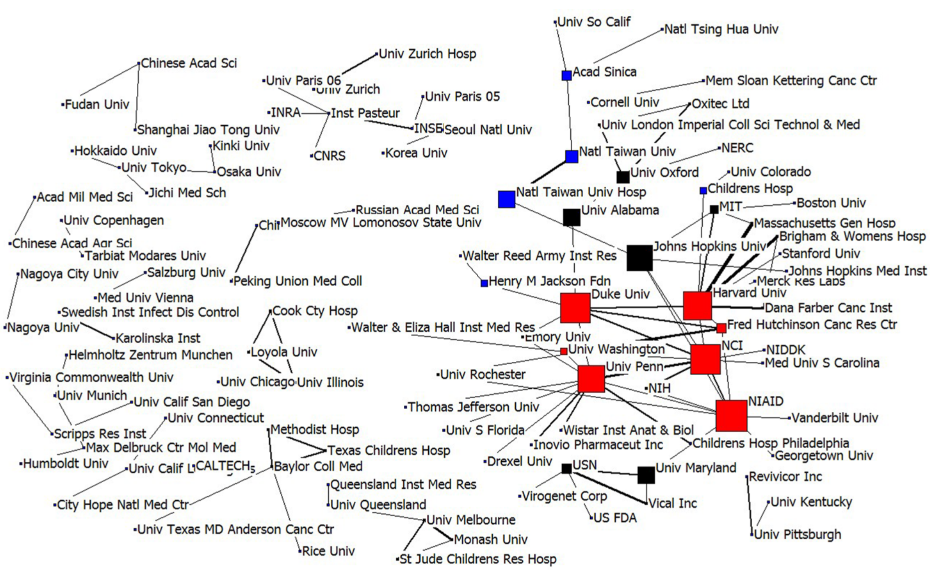

Figure 2. K core network of GEV cooperation-based publications in China domestic.

Union Medical College) and the Russian Academy of Medical Sciences. The elicited results show that these seven institutions are major cooperative institutions in basic research on GEVs. There are close cooperative relationships within the three cooperative networks. At the same time, cooperative relations between research institutions are often frequently compared with these universities.

4.3 The key impact factors for the GEV in patent-to-product transformation

A lot of research analyzes the factors blocking the path between R&D results and commercial production and the impact of those factors on patent-to-product transformation. In the area of GEVs, there are many impact factors affecting the decision-making at commercial enterprises in terms of how to acquire and produce the vaccine. Nine patented technology-effect factors considered for the genetic vaccine in its patent-to-product transformation are included in this study: good immunogenicity, production readiness, high safety, good profitability, low cost of production, high-efficiency expression, high purity, active immunization, and good repeatability.

We construct a two mode network of the institutions that have more than 10 GEV patent applications and nine technology-effect, as shown in Figure 3. The larger the institution nodes in the graph, the more technology-effect the institution's patents have; the larger the technology-effect nodes, the more institutions there are involved in this technology-effect; the thicker connection line between the nodes indicates that the organization has advantages in this technology-effect.

Here, we use community discovery to analyze different technology-effect communities. The community in the network reflects the local characteristics of the network and the interrelation among its internal nodes. Different communities have different structural characteristics. The nodes in the same community are closely connected with each other and the connections among the communities are relatively sparse. The structure or attributes of the same community have some similarities (Newman, 2004). The patents applied by the patent agencies in the community have the same technology-effect and these institutions show a closer connected status. The fast unfolding community discovery algorithm proposed by Blondel et al. (2008), whch is a non-overlapping community discovery algorithm based on a block modulus. The two mode network is divided into five communities: #1, #2, #3, #4, and #5. The patents applied by patent agencies in community #1 have two technology-effect factors: production-readiness and high-efficiency expression, in #2, active immunization, in #3, high purity, good repeatability, and good profitability, in #4, low cost of production, and in #5, both good immunogenicity and high safety.

Figure 3. Two mode network of GEV patent applications and technology-effect.

To achieve the commercialization of the GEV, all the nine technology-effect factors need to be well developed. There are interdependencies among the agencies in five communities, that is, similarities in technology-effect. Therefore, these patent application agencies have the basis for cooperation with each other.

In addition, the figure shows that the patents applied for by the patent agencies in communities #2 and #4 have fewer patents outside their communities, indicating that the patents of these communities are different from those of other community organizations. In addition, the UNIV PLA THIRD MILITARY MEDICAL organization, except for the unconnected patented effect in #2, has links to the technology-effect factor of patents in other communities, indicating that the patents applied by UNIV PLA THIRD MILITARY MEDICAL are functionally equivalent to those in other communities. The overlap is so strong that this agency may have a greater potential for cooperation with patent agencies in other communities.

4.4 The identification result of IURC partners based on the innovation chain

(1) Competitiveness analysis in basic research

The top 19 institutions with a high number of SCI papers in GEVs in China (Table 2) include five scientific research institutes (accounting for 26.3%). The total number of papers was 72 (44.4%), and the average citation number was 10.36. The

Table 2. Publication of SCI papers of domestic GEV by the amount of top19 institutions.

No.	institution	Province	Number of papers	citations	Cited amount of average article	Number of CNCI
1	Chinese Academy of Sciences	Beijing	26	240	9.23	0.96
2	Chinese Academy of Agricultural Sciences	Beijing	25	219	8.76	0.87
3	Chinese Academy of Military Medical Sciences	Beijing	12	124	10.33	0.69
4	The Fourth Military Medical University	Shaanxi	12	68	5.67	0.39
5	Huazhong University of Science and Technology	Hubei	10	79	7.90	0.48
6	Shanghai Jiao Tong University	Shanghai	9	91	10.11	0.41
7	Zhejiang University	Zhejiang	9	67	7.44	0.93
8	Shanghai Institutes for Biological Sciences	Shanghai	8	109	13.63	1.07
9	Sichuan University	Sichuan	8	37	4.63	0.36
10	Peking University	Beijing	7	52	7.43	0.52
11	The Second Military Medical University	Shanghai	7	42	6.00	0.71
12	Huazhong Agricultural University	Hubei	5	58	11.60	0.73
13	China Medical University	Liaoning	5	38	7.60	0.73
14	South China Agricultural University	Guangdong	4	51	12.75	1.53
15	Jilin Agricultural University	Jilin	4	47	11.75	1.45
16	Central South University	Hunan	4	42	10.50	0.6
17	China Agricultural University	Beijing	3	46	15.33	0.7
18	Chongqing Medical University	Chongqing	3	38	12.67	0.49
19	The National Center for Nanoscience and Technology of China	Beijing	1	54	54.00	6.23

results show that the number of scientific research institutes in the field of domestic GEVs is small but the number of fundamental research studies is large and has a high impact, which constitutes the backbone of basic research in the field of GEVs. In addition to the five listed institutions, the other four institutions, Huazhong Agricultural University, China Agricultural University, Jilin Agricultural University, and China Agricultural University, account for a total of 16 papers (9.9%) with an average citation number of 12.65. Although the number of papers from these agricultural universities is very small, despite the high research influence, these four agricultural universities play an important role in the field of basic research on gene vaccines in China. Moreover, most of the remaining colleges and universities are national key institutions with strong capacities in scientific research. Therefore, these colleges and universities constitute the main research power in the research area of the GEV.

Among the top 19 institutions, there are four institutions whose CNCI value exceeded 1, including two research institutes and two agricultural universities. The citations of papers from these four institutions exceeded the global level. Among them, the CNCI value for the The National Center for Nanoscience and Technology of China was 6.23. The citation of the paper was 6.23 times the global average. There were also 15 institutions (78.9%) below 1, indicating that most of these papers were not influential.

(2) Competitiveness analysis in application research

There are 31 institutions that have more than 10 patents related to GEVs with the total patent number equal to 539 (Table 3). These institutions can be divided into three categories: universities, research institutions, and enterprises. Among them, there are 14 universities (45.2%) with 270 patents, accounting for 50% of the total patents of 31 institutions. There are 12 research institutes (38.7%) with 200 patents (37.1%), and five enterprises (16.2%) with 69 patents (12.8%). This indicates that the universities and research institutes are still the major R&D players in Chinese domestic GEV research. Compared to basic research, the number of patents held by enterprises is only a small proportion of the total patents. However, enterprises are beginning to play a role in the execution of research.

(3) Competitiveness analysis in transfer and transformation

The State Food and Drug Administration of China (CFDA) has implemented a tightly controlled policy on vaccine production, sales, and other aspects. Enterprises have the right to produce and sell vaccines only once they obtain approval from the CFDA. The CFDA database provides the record information for all eligible enterprises. The data regarding all vaccine enterprises in China collected from the CFDA database show that, at present, there are 58 enterprises with vaccine production qualifications in the domestic market, with 10 GEV manufacturers but only five GEVs types have been listed. Compared to the number of domestic GEV patents, the number of GEV patents that have been transformed into products is much smaller (Table 4).

There are four companies with GEV patents in China, and only one of them can produce the GEV, a fact that also confirms that the rate of patents being transformed into products is still low (Table 5).

(4) Competitiveness analysis in commercialization and industrialization

Vaccine sales must be under the batch release control system in China, which means that vaccine inspection by the CFDA is compulsory before it goes into the

Table 3. Major GEV patents owners in domestic China (institutions have more than 10 patents).

No.	Patent agencies	Province	Number of Patents
1	Fudan University	SH	51
2	Third Military Medical University	CQ	45
3	Lanzhou Veterinary Research Institute, Chinese Academy of Agricultural Sciences	GS	39
4	Harbin Veterinary Research Institute,CAAS	HL	29
5	Society for Microbiology of Military Medical College	BJ	21
6	Huazhong Agricultural University	HB	21
7	Nanjing Agricultural University	JS	19
8	The Fourth Military Medical University	SN	18
9	Aventis Pasteur Company	GD	17
10	Institute of Basic Medical Sciences, Academy of Military Medical Sciences	BJ	17
11	Jiangsu Academy of Agricultural Sciences	JS	17
12	Beijing Kaiyin Biological Technology Co., Ltd.	BJ	16
13	Jilin University	JL	16
14	The Second Military Medical University	SH	16
15	Sichuan Agricultural University	SC	16
16	Institute of medical biology of Chinese Academy of Sciences	BJ	13
17	Merial Co., Ltd.	JX	13
18	Pulaike Biological Engineering Co., Ltd.	HN	13
19	Shanghai Human Genome Research Center	SH	13
20	South China Agricultural University	GD	13
21	Wuhan University	HB	12
22	Institute of Microbiology, Chinese Academy of Sciences	BJ	11
23	China Agricultural University	BJ	11
24	Xiamen University	FJ	11
25	Zhejiang University	ZJ	11
26	Institute of Medical Biotechnology of Chinese Academy of Medical Sciences	BJ	10
27	Yuanlun Biotechnology Co., Ltd.	CQ	10
28	Center for Parasitic Diseases Control and Prevention	SH	10
29	Institute of Military Veterinary Medicine, Academy of Military Medical Sciences	JL	10
30	Shanghai Veterinary Research Institute, CAAS	SH	10
31	Zhongshan University	GD	10

domestic market or is exported. Thus, the amount of the batch release vaccine is equal to its commercialization scale. Such data are difficult to obtain, and thus, we counted and analyzed quantity features only. There are five types of commercial vaccines in the domestic market. Among them, the recombinant hepatitis B vaccine (Saccharomyces cerevisiae) has the largest proportion in reference to the scale of commercialization, accounting for 61.9%. This shows that the recombinant hepatitis B vaccine is the most mature and extensively used GEV in China's domestic market (Table 6).

There are 10 enterprises that have achieved commercialization of vaccines in China, and two enterprises meet the standard of producing the GEV: the Lanzhou

Table 4. GEV types in domestic China.

No.	Manufacturers	Genetically Engineered Vaccine	Province
1	Beijing Tiantan Biological Products Co., Ltd.	Recombinant Hepatitis B Vaccine (Saccharomyces cerevisiae)	Beijing
2	Shenzhen Kangtai Biological Products Co., Ltd.	Recombinant Hepatitis B Vaccine (Saccharomyces cerevisiae)	Guangdong
3	Hualan Biolocical Engineering, Inc.	Recombinant Hepatitis B Vaccine (Hansenula polymorpha)	Henan
4	Dalian Hissen Bio-pharm.Co.,Ltd.	Recombinant Hepatitis B Vaccine (Hansenula polymorpha)	Liaoning
5	Beijing Waldorf Shield Biotechnology Co., Ltd.	Recombinant Hepatitis B Vaccine (CHO cell)	Beijing
6	Lanzhou Institute of Biological Products Co., Ltd.	Recombinant Hepatitis B Vaccine (CHO cell)	Gansu
7	NCPC GeneTech Biotechnology Development Co., Ltd.	Recombinant Hepatitis B Vaccine (CHO cell)	Hebei
8	Wuhan Institute of Biological Products Research Co., Ltd.	Recombinant Hepatitis B Vaccine (CHO cell)	Hubei
9	Xiamen Innovax Biotech Co., Ltd.	Recombinant Hepatitis E Vaccine (Escherichia coli)	Fujian
10	Shanghai United Cell Biotechnology Co., Ltd.	Recombinant B subunit / bacterial cholera vaccine (enteric-coated capsule)	Shanghai

Table 5. GEV Production of enterprise with relevant patents.

Vaccine manufacturer	Number of genetically engineered vaccine patents	Number of genetically engineered vaccine
Liaoning Chengda Co., Ltd.	2	0
Liaoning Yisheng BioPharma Co., Ltd.	3	0
Xiamen Innovax Biotech Co., Ltd.	3	1
Changchun BCHT Biotechnology Co.	2	0

Institute of Biological Products Company and the Wuhan Institute of Biological Products Research Company. However, they have not produced GEVs, which indicates that they have not yet achieved commercialization of a GEV.

Among these 10 enterprises are the Shenzhen Kangtai Biological Products Company, the Beijing Tiantan Biological Products Company, the Dalian Hissen Bio-pharm Company, and the NCPC GeneTech Biotechnology Development Company with a high commercialization concentration degree, accounting for 90.4%. Meanwhile, Glaxo Smith Kline and Berna Biotech AG are foreign enterprises accounting for 4.3% of the total amount of the commercialization scale.

4.5 The recognition results of the potential IURC partners

Analyzing the features of the domestic GEV industry in China, we can see that this industry presents the pattern of a comprehensive innovation chain. Thus, we

Table 6. Total proportion of GEV commercialization scale in domestic China (2007–2015).

No.	Vaccine manufacturer	Genetically Engineered Vaccine	Proportion of scale	Region (Country)
1	Shenzhen Kangtai Biological Products Co., Ltd.	Recombinant Hepatitis B Vaccine (Saccharomyces cerevisiae)	33.7%	Guangdong
2	Beijing Tiantan Biological Products Co., Ltd.	Recombinant Hepatitis B Vaccine (Saccharomyces cerevisiae)	24.3%	Beijing
3	Dalian Hissen Bio-pharm.Co., Ltd.	Recombinant Hepatitis B Vaccine (Hansenula polymorpha)	19.7%	Liaoning
4	NCPC GeneTech Biotechnology Development Co., Ltd.	Recombinant Hepatitis B Vaccine (CHO cell)	12.7%	Hebei
5	Glaxo Smith Kline	Recombinant Hepatitis B Vaccine (Saccharomyces cerevisiae)	3.9%	Belgium
6	Hualan Biolocical Engineering, Inc.	Recombinant Hepatitis B Vaccine (Hansenula polymorpha)	2.5%	Hennan
7	Shanghai United Cell Biotechnology Co., Ltd.	Recombinant B subunit / bacterial cholera vaccine (enteric-coated capsule)	1.8	Shanghai
8	Beijing Waldorf Shield Biotechnology Co., Ltd.	Recombinant Hepatitis B Vaccine (CHO cell)	0.9	Beijing
9	Berna Biotech AG	Recombinant Hepatitis B Vaccine (Hansenula polymorpha)	0.4	Switzerland
10	Xiamen Innovax Biotech Co., Ltd.	Recombinant Hepatitis E Vaccine (Escherichia coli)	0.1	Fujian

can infer that there will be a higher possibility of cooperation among enterprises, universities, and research institutes in the IURC partnership.

In the basic research phase in the innovation chain in the domestic GEV industry of China (Table 7), the selection of the category types for the IURC for institutions can be divided into research institutions, agricultural universities, and comprehensive research universities. In the applied research phase, enterprises begin to join the innovation chain, and most of them are the main participants in the transfer and transformation, commercialization, and industrialization phases. The comprehensive innovation chain needs to be populated with all types of industries, universities, and research innovations. At present, there are no enterprises in basic research. This indicates that enterprises have a higher possibility to join basic research networks. There are five elite enterprises in the applied field of GEVs: Aventis Pasteur Company, Beijing Kaiyin Biological Technology Company, Merial Company, Pulaike Biological Engineering Company, and Yuanlun Biotechnology Company. However, the companies that do not have CFDA qualification, and the other 58 companies that are qualified, own fewer patents. Therefore, considering knowledge transformation and the abilities that are complementary to the process of transformation, the five nonqualified companies and 58 qualified companies are more likely to be candidates for cooperation.

Table 7. Category types of IURC in GEV innovation chain in domestic China.

Basic research	Applied research	Transfer and transformation	Commercialization and industrialization
Research institutes	Research institutes	enterprise	Enterprise
Agricultural University	Agricultural University	N/A	N/A
comprehensive research university	comprehensive research university	N/A	N/A
N/A	enterprise	N/A	N/A

From the spatial distribution of the innovation chain process, the institutions that have greater potential to cooperate are those that have high relevance and complementary technology capacities, are in close geographical position, and are different types of institutions. GEV R&D and production institutions in Guangdong, Beijing, and Shanghai comprise the complete innovation chain. Each institution in the innovation chain in the three locations has high complementary capacities, which shows that IURC institutions in Beijing, Shanghai, and Guangdong have greater cooperative potential. Compared to the other two areas, there are more industry-university-research institutions in Beijing; these types of institutions vary, the possibility of choosing collaborative partners is, thus, higher, and the spatial distances among these institutions are smaller. Therefore, the GEV research institutions in Beijing have increased cooperative potential.

(1) In the Guangdong province, there are more cooperation possibilities among the South China Agricultural University, the Aventis Pasteur Company, the Zhongshan University, and the Shenzhen Kangtai Biological Products Company. Specifically, the quality of both the basic and applied research of the South China Agricultural University is high, while the corresponding research ability of Shenzhen Kangtai Biological Products Company as a commercial and industrial institution is weaker. Thus, there are many more possibilities for cooperation between the South China Agricultural University and the Shenzhen Kangtai Biological Products Company in view of the convenience of the geographical location and the complementary capacities.

(2) In Beijing, the National Center for Nanoscience and Technology, the Chinese Academy of Medical and Biological Science, and the Chinese Academy of Microbiological Research all belong to the Chinese Academy of Sciences. Considering the organizational relations and the convenience of geography, there are more possibilities for cooperation in basic and applied research in GEV among these institutions.

(3) In Shanghai, the Second Military Medical University is stronger in basic and applied research, while, as a commercial and industrial institution, the research ability of the Shanghai United Cell Biotechnology Company is weaker. Therefore,

there are many more possibilities for cooperation between the Second Military Medical University and the Shanghai United Cell Biotechnology Company because of the geographical convenience and the complementary capacities.

Table 8. The spatial distribution of GEV institutions in domestic China.

Region	Basic Research Institute	Applied Research Institute	Commercialization and industrialization organization
Guangdong	South China Agricultural University	Aventis Pasteur Company South China Agricultural University Zhongshan University	Shenzhen Kangtai Biological Products Co., Ltd.
Beijing	Chinese Academy of Sciences Academy of Military Medical Sciences Chinese Academy of Agricultural Sciences Peking University The National Center for Nanoscience and Technology, Chinese Academy of Sciences	Institute of Microbiology of Military Medical College Institute of Basic Medical Sciences, Military Medical College Beijing Kaiyin Biological Technology Co., Ltd. Institute of medical biology of Chinese Academy of Sciences Institute of Microbiology, Chinese Academy of Sciences China Agricultural University Institute of Medical Biotechnology of Chinese Academy of Medical Sciences	Beijing Tiantan Biological Products Co., Ltd. Beijing Waldorf Shield Biotechnology Co., Ltd.
Liaoning	China Medical University	N/A	Dalian Hissen Bio-pharm. Co., Ltd.
Heibei	N/A	N/A	NCPC GeneTech Biotechnology Development Co., Ltd.
Henan	N/A	Pulaike Biological Engineering Co., Ltd.	Hualan Biolocical Engineering, Inc.
Shanghai	Shanghai Jiao Tong University Shanghai Institutes for Biological Sciences, Chinese Academy of Sciences The Second Military Medical University	Fudan University The Second Military Medical University Shanghai Human Genome Research Center Center for Parasitic Diseases Control and Prevention Shanghai Veterinary Research Institute, Chinese Academy of Agricultural Sciences	Shanghai United Cell Biotechnology Co., Ltd.
Fujian	N/A	Xiamen University	Xiamen Innovax Biotech Co., Ltd.

Note. In the basic research phase, the Chinese Academy of Sciences is the generic name of all Chinese Academy of Sciences but excludes The National Center for Nanoscience and Technology, Chinese Academy of Sciences and Shanghai Institutes for Biological Sciences, and the Chinese Academy of Sciences. The Chinese Academy of Military Medical Sciences and the Chinese Academy of Agricultural Sciences are also the generic names for all their subordinate organizations.

Table 9 lists the types of vaccine production enterprises in domestic China. There is fierce competition among the enterprises since they produce the same types of vaccines, which leads to few cooperation possibilities. The Shenzhen Kangtai Biological Products Company, the Beijing Tiantan Biological Products Company, and Glaxo Smith Kline all produce recombinant hepatitis B vaccines (Saccharomyces cerevisiae), so there are few cooperative possibilities. At the same time, the cooperation possibilities are also slim among Hualan Biological Engineering, the Dalian Hissen Bio-pharm Company, Berna Biotech AG, as well as for the NCPC GeneTech Biotechnology Development Company and the Beijing Waldorf Shield Biotechnology Company.

Table 9. Types of vaccine production enterprises in domestic China.

Genetically Engineered Vaccine	Vaccine manufacturer
Recombinant Hepatitis B Vaccine (Saccharomyces cerevisiae)	Shenzhen Kangtai Biological Products Co., Ltd., Beijing Tiantan Biological Products Co., Ltd., Glaxo Smith Kline
Recombinant Hepatitis B Vaccine (Hansenula polymorpha)	Hualan Biolocical Engineering, Inc., Dalian Hissen Bio-pharm. Co., Ltd., Berna Biotech AG
Recombinant Hepatitis B Vaccine (CHO cell)	NCPC GeneTech Biotechnology Development Co., Ltd., Beijing Waldorf Shield Biotechnology Co., Ltd.
Recombinant B subunit / bacterial cholera vaccine (enteric-coated capsule)	Shanghai United Cell Biotechnology Co., Ltd.
Recombinant hepatitis E vaccine (Escherichia coli)	Xiamen Innovax Biotech Co., Ltd.

The Chinese Academy of Sciences and the Agricultural and Military Medical Sciences are the main research institutions in basic and applied research, and they are both open-types. Thus, the possibility of related cooperation among these science academies, or internally within the same organization, is greater. Considering geographical-spatial convenience, these three academies have a much higher possibility of cooperating with Beijing enterprises on transfer and transformation, commercialization, and industrialization. Meanwhile, the Hebei province, which is adjacent to Beijing, does not have institutions with a strong background in genetic engineering in basic or applied research. Therefore, the NCPC GeneTech Biotechnology Development Company in Hebei tends to seek more research-related cooperation with institutions in Beijing, and these three academies of sciences will constitute preferred cooperative choices.

Although the recognition results of the potential partners can be effective references for cooperation, whether the institutions will actually cooperate is still subject to a number of additional factors.

5 Conclusion

According to the rules of scientific collaboration, and combining the economic factors in IURC, this paper uses the theory of knowledge potential and spillover to analyze the motivations and conditions of IURC. We implement a recognition method of the objects of IURC based on knowledge spillover effects in the innovation chain. When the innovation chain focuses on the technology chain, it targets the transformation and application of innovation elements in different links at the same time. The analysis of industrial competitive intelligence based on the innovation chain is dependent on the entire process of innovation activity, including the analysis of industry and technological innovation that considers both qualitative and quantitative analyses, and comprehensively and systematically analyzes all industrial activity. Using an empirical analysis of potential IURC in the field of GEVs, this paper also investigates the feasibility of these methods.

Compared with previous studies, this study focuses more on the cooperative behavior at the micro level, so the conclusion will be of higher reference value. However, the research methods and conclusions of this study also have limitations. The cooperation across production, study, and research is a complex social phenomenon. The factors affecting the cooperation across industry, universities, and research institutions go far beyond the four hypothetical conditions presented here. Organizations that satisfy the above conditions may have competitive relationships. Ultimately, the pursuit of competition or cooperation will involve more economic interests and the decision-makers' comprehensive consideration. Further, in this study, the overall approach is shaped by the theoretical concept of an innovation chain, a linear innovation model with specific types or stages of innovation activities at each phase of the chain. As such, this may overlook important feedback mechanisms in the innovation process. In the future, we will also consider non-linearity innovation theory, which can offer more feedback information. Moreover, future IURC research requires more attention to the phenomenon of cooperative practices from the micro viewpoint to establish a specific and thorough optimization strategy with more feasibility and operability.

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Author Contributions

Haiyun Xu (xuhy@clas.ac.cn, corresponding author) proposed the research idea, designed the research, drafted and revised the manuscript. Chao Wang (wangchao2015@mail.las.ac.cn) wrote the program to process the data. Kun Dong (dongkun@mail.las.ac.cn) performed the research and revised the manuscript. Rui Luo (luorui@mail.las.ac.cn) did the data analysis. Zenghui Yue (yzh66123@126.com) performed the research and revised the manuscript. Hongshen Pang (phs@szu.edu.cn) performed the research and revised the manuscript.

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