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The inventive activities and collaboration pattern of university–industry–government in China based on patent analysis

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Abstract China's economy and technology have experienced spectacular growth since the Opening-up Policy adopted in 1978. In order to explore the innovation process and development of China, this study examines the inventive activities and the collaboration pattern of university, industry and government (UIG) in China. This study analyzes the Chinese patent data retrieved from the United States Patent and Trademark Office. Three models of UIG relations which represent different triple helix configurations are introduced. According to the property of patent assignee, patent ownership can be divided into three types: individuals, enterprises, and universities and research institutes. Furthermore, enterprises can be classified into state-owned enterprise (SOE), private-owned enterprise (POE) and foreign enterprise (FE). The corresponding relationship of patent ownership with UIG is set up. Through analyzing the issued year, it is found that the inventive activities of China have experienced three developmental phases and have been promoted quickly in recent years. The achievement of innovation activities in China primarily falls on the enterprise, especially FEs and POEs. The innovation strengths of the three development phases have shifted from government to university and research institute and then industry. According to co-patent analysis, it is found that the collaboration between university and industry is the strongest and has been intensified in recent years, but other forms of collaboration among UIG have been weak. In addition, an innovation relation model of China was set up. The evolution process of innovation systems was explored, from etatistic model, followed by improved "laissez-faire" model, and then shifting toward triple helix model.

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Introduction

Since the adoption of the Opening-up Policy in 1978, China has achieved an astounding growth in both economy and technology in the past three decades, and has aspired to be the center of world's technology/innovation rather than "World's Factory." China has initiated numbers of programs to reform its innovation system. In 2006, China announced its "Guideline for the National Medium- and Long-term Science and Technology Development Programs (2006–2020)" for the next 15 years. The focus is to emphasize the strategic role of technology innovation and to lay out a number of goals and specific measures so as to realize China's aspiration to become an innovation center by 2020 (Ma et al. 2009).

Over the past few years, innovation studies and related fields have started to put considerable emphasis on a systemic view. The interaction between the elements of innovation systems has drawn more and more attention (Granberg 1996; Lundvall 1992; Nelson 1993). The past 20 years saw a pattern of increasing collaboration in inventive activities across the world, which indicates that the world has begun to enter the inceptive stage of ''Techno-globalism'' (Ma and Lee 2008).

As for the innovation system, academic circles have proposed several types of innovation model. For instance, the triple helix innovation pattern reflects the relationship of university, industry and government (UIG) (Etzkowitz and Leydesdorff 1995). Studies on the evolution of innovation systems have shifted their concern from merely description of early static activity to dynamic transformation of each element based on the knowledge transmission network. The triple helix denotes a transformation in the relationship among UIG as well as within each sphere. The triple helix innovation system theory emphasizes the interaction and collaboration of UIG with each entity keeps its independence at the same time (Etzkowitz and Leydesdorff 2000; Etzkowitz 2003).

This study explores innovation activities and collaboration pattern of UIG in China based on patents analysis. The data source selection and search will be discussed first. Then the analytical method will be presented. Theoretical mode of innovation which reflects the UIG relations and patent analysis approach constitute the analytical guideline throughout the research. An overview of Chinese patents is also drawn, such as inventive activities is explored and main innovation strength is discussed. Next, the inventive activities of UIG in China are studied. Distribution of patents and the trend of development of UIG are analyzed. Moreover, the UIG distributions in different phases have been explored. Technological inventive collaboration status of UIG has been analyzed as well. In this section, patent assignee number distribution is explored, and the UIG relations are shown according to patent ownership analysis. Based on the inventive activities and collaboration patterns, the innovation relation model of UIG in China could be built and the evolution of innovation systems would be analyzed deeply. In the conclusion part, the results will be displayed and discussed.

Literature review

Innovation system

The national system of innovation approach usually considers the firm as a leading role in innovation, and the university as a supportive structure of innovation, providing trained persons, research results, and knowledge to industry. The triple helix thesis states that the university can play an enhanced role of the innovation in the increasingly knowledge-based societies (Meyer et al. 2003). Introduction of firms with more advanced innovations has relied to a higher extent on R&D and patents. They frequently cooperate with universities and research organizations. Furthermore, the employment of researchers is identified as a key factor enhancing knowledge interactions between firms and universities (Toedtling et al. 2009).

Based on new technologies originated from academic research, the university–industry relation has been changing. The impact of university–industry relations have on research activity has also been studied. The research of Manjarrés-Henríquez et al. (2008) found that university–industry relations have performed a positive effect on university scientific productivity only when they are based on the development of R&D contracts, and when the funds obtained through these activities which are lower than 15% of researcher's total budget. Atlan (1987) pointed out that R&D collaboration is an important mode in university–industry relations. In-house R&D is regarded as an important source of knowledge of innovation. Thereby, there is a strong reason to build an environment of cooperation between enterprises and research institutes (Klitkou et al. 2007). Leroy and Doerig (2008) discuss the benefits of academia–industry cooperation, and the influential reasons of the cooperation partner set-up between industry and university. The results show that in addition to scientific activities, the ownership of intellectual property must be considered in the context of partnerships between industry and academia. Patent as an important technology output and intellectual property could affect the attitude of academia about university–industry cooperation (Lee 1996). Meyer et al. (2003) combined patent analysis with an inventor survey to gain useful indicators in a triple helix context, and explore the collaboration relationship of industry and university.

On the other hand, innovation process from R&D investment to product output has the risk and uncertainness, so the invention motive will be insufficient if only relying on universities or enterprises, then the government ought to participate in the innovation process. Many developed countries have paid special attention to the participation of government in innovation process (Etzkowitz and Leydesdorff 2000). The general way is that government support is ascended to national policy or strategy height, and set up a system which encourages the collaboration between university and industry. For example, the Office of Science and Technology (OST) of England put effort forward to 'Link Collaborative Research Scheme' in 1986. The aim of this scheme is to promote the cooperation of university and industry by R&D fund provided by government. The United States also has many research fund organizations supported by government, such as National Science Foundation (NSF), National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), etc.

Patent collaboration

An available solution for this tough situation is to use patent data to measure the inventive activities and collaboration status of UIG. Patent is one kind of open and available information resource. Patent data contains standardized information related to new ideas and technological developments, so they have been treated as the most important output indicators of technology change and innovative activities (Pilkington et al. 2002; Frietsch and Grupp 2006). Patent analysis has also become the focus of many tools and techniques to measure innovation (Belderbos 2001; Lin and Lin 2002; Pilkington 2004; Chen et al. 2005; Hanel 2006). Furthermore, research has shown that patent analysis provides valuable information on technology collaborative efforts (Etemad and Seguin-Dulude 1987; Etemad and Lee 1999). Information fields of a patent application package often produce valuable insights about research collaborations and inventive activities, such as inventor identity and assignee information. Thus the analysis of patent data offers an important tool to explore the technology collaborative efforts. Patent activity in China grew by 470% from 1997 to 2006, outpacing all other countries in terms of growth (Bonsor 2007). As a result, patent data provides an effective tool to evaluate China's efforts in reforming its innovation system and the progress it has made.

Thus, patent collaboration has turned as one of the methods to measure the output of innovation system. Gao et al. (2011) investigated patent collaborative knowledge production in China and its implications for the national and regional innovation system of China. Chen and Guan (2011) have researched the patent collaboration performance of Chinese organizations and regions in the field of biotechnology. They found there is an intimate depend on foreign knowledge, especially the knowledge of multinational firms and universities of US. Otherwise, Ortega (2011) investigated the collaboration patterns in the networks of patents. The regression analysis found that the national collaboration can strongly, effectively transfer the patents. Regarding the impact of university–industry collaborations, prior ties and geographical distance between universities and firms are both positively related to the achievement of higher innovative outcomes (Petruzzelli 2011). Besides, according to the government-funded research and the move of supporting graduate students, universities have precipitated to collaborate with firms (Boardman and Ponomariov 2009).

Besides inventive activities research of each type of innovation entity, collaborations of UIG are also focused. Collaboration is an inherent aspect of the research activity, because the information exchange reinforces the discussion and the production of new knowledge (Katz and Martin 1997). Collaboration pattern plays an important role in the national innovation system. Though the interconnections of UIG of innovation system have been recognized, the measurements of innovation contribution and collaboration status of UIG are difficult since relevant technology and R&D input and output information usually keep secret.

Three models of UIG relations

A triple helix of the relations among UIG is like a key component of national or multinational innovation strategy in the late twentieth century. Sábato and Mackenzi (1982) noted that triangle model plays a role of technical research, production, and the guider of policy development, government is privileged to determine the direction of technology development. Etzkowitz and Leydesdorff (2000) conceptualize the underlying model as analytical difference from the national systems of innovation approach, which considers the firm as the leading role in innovation. The evolution of innovation systems and the current conflict should be taken in the relations of university and industry, which has reflected varying institutional arrangements in the relations among UIG. UIG relations can be considered as a triple helix of evolutional networks of communication. There are three typical models of triple helix configurations which reflect different relations of UIG.

In the first model (Fig. 1a), government plays a dominant role, encompasses university and industry, and directs the relations between them. Triple Helix I is largely viewed as a failed developmental model. With a tiny room for "bottom-up" initiatives, innovation was discouraged rather than encouraged.

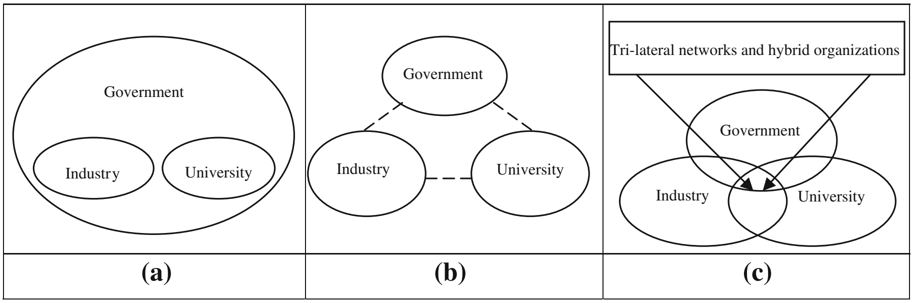

Fig. 1 Three models of UIG relations. **a** An etatistic model of UIG relations, **b** a "laissez-faire" model of UIG relations and **c** a triple helix model of UIG relations. *Source* Etzkowitz and Leydesdorff (2000, p. 111)

A second policy model (Fig. 1b) consists of separate institutional spheres with strong borders divided and highly circumscribed relations among the spheres. This configuration can be considered as improved *laissez-faire* policy in order to adjust the overweight of government in the relations of UIG. Triple Helix II entails a policy of laissez-faire, nowadays advocated as shock therapy to reduce the role of the state in Triple Helix I.

Finally, the third model has generated a knowledge infrastructure in terms of overlapping institutional spheres, with each role taken from the other and with hybrid organizations emerging at the intersection (Fig. 1c). The common objective is to realize a positive innovative environment based on the interaction of UIG.

For a further discussion, Etzkowitz and Leydesdorff (2000) classified triple helix innovation pattern into etatistic model, laissez-faire model of socialism countries which separate institutional spheres with strong borders divided. Triple helix model is the overlapping institutional spheres with hybrid organizations emerging at the intersections of etatistic model. The nation encompasses academia and industry as well as directs the relations among them. However, it lacks the motivation of bottom-up creativity. The *laissez-faire* model is advocated as frightened therapy to reduce the governmental roles in etatistic model. Most countries and regions have tried to attain the form of triple helix model nowadays, taking a behavior of encouragement instead of control. Leydesdorff and Meyer (2003) pointed out there are three functionally different sub-dynamics in the system of knowledge-based innovation: economic exchanges on the market, geographical variations, and the organization of knowledge. The above-mentioned dynamics have non-linear influences on the innovation system.

Recent study of Dolfsma and Leydesdorff (2008) is based on the Shannon information theory, which employed probabilistic entropy statistics to discuss the knowledge base of economy. The result shows that medium-tech industry has a greater contribution than high-tech industry does on knowledge creation.

Systems of national innovation depend on various factors such as historical situation, policy guidance, economy development, natural resources, etc. The process of innovation is also a process of dynamic transformation, so the theoretical models of UIG vary in countries and regions during different phases of development. For example, the model of Triple Helix I could be found in the former Soviet Union and Eastern European countries under "existing socialism". China is known as a developing socialist country, but the economy and technology of China have experienced spectacular growth, differing itself from many other socialist countries with weaker innovation ability under the etatistic model, i.e. Triple Helix I. What leads to the phenomenon and which kinds of innovation models of UIG have been adopted and transformed in China will be discussed in the study.

Data and methodologies

Data selection: the USPTO patent database

The patent data were retrieved from the United States Patent and Trademark Office (USPTO) granted patent database and downloaded from an online site (http://www.uspto.gov) on November 1st, 2010. The USPTO is the federal agency responsible for granting U.S. patents and trademarks registration. Founded in 1802, the USPTO has provided more than 4,000,000 patents since 1976. Here are the reasons for choosing USPTO patent database: First, the U.S. patents are representative of the world's technology. Approximately half of the inventions of U.S. patents are foreign-owned, and each country's invention patents issued in the U.S. are roughly proportional to their country's Gross Domestic Product (GDP) (Narin 1991). Second, the patent database of the USPTO suffers the least biases in patent statistics, especially during a long period of time when sufficient numbers of technological classes are included. USPTO can provide a proper database for study, as Scherer (1984) suggested in his "law of large numbers." Third, taking the geographical factor into consideration, the USPTO patents provide the detail address information of assignees and inventors which are essential to analysis regarding geopolitically-related collaboration.

In order to search Chinese patents granted in the U.S., China has been chosen in the field of assignee country. If the assignee country field was null, the field of inventor country would be searched. Finally, 7,841 Chinese patents were retrieved from the USPTO.

Patent analysis

Patent statistics is publicly available, updated, and provides very specific and detailed information for tracing inventive activities over time. Furthermore, patent statistics is the only formally and publicly verified output of measurement of inventive activities. For the reasons above, researchers apply patent statistics and particularly deem it as the measure of innovation and inventive activities (Acs and Audretsch 1989; Tong and Frame 1994; Ma and Lee 2008). In this study, we also adopt patent statistics as the measure of inventive activities and collaboration pattern of UIG.

Three fundamental works need to be completed before applying the statistics of patent.

Categories of patent assignee

Several fields of information in a patent document yield valuable insights of inventive activities. The fields of inventor or assignee have been frequently used as the measure for the relationships of collaboration. The inventors of a patent are the creators of innovation, while assignees are generally associated with the commercial right of a patent. Since the objects of the research are UIG, patent assignees naturally will be analyzed. The patent application can tell the nationality of an assignee from its address. Categories of patent assignees are listed as follows.

Case I: Single assignee This case means there is only one assignee in the patent, i.e. the right of the patent is exclusive. The inventive activity is only conducted by only one assignee without any collaboration.

Case II: Multiple assignees It is possible to assign a given patent with multiple assignees. The inventive activity and patent right are conducted and shared by all assignees. The relationships of collaboration are constructed by them. The collaboration pattern can be measured by analysis of co-patents.

Case III: None of assignee is declared in the patent application This case simply means that the information field of assignee is left blank in the patent application. It is available to leave the field of assignee blank according to the permission of patent office (i.e., "no assignee"). The Patent Law of America rules that only individual inventor can file patent, and the corporation could obtain the patent right through transference. Therefore, a patent with "no assignee" can be viewed as owned by individual person.

The authority control of patent assignee

The task of authority control is necessary because one assignee probably has various forms of names, such as initials, a full name, a name of its subsidiary company, etc. Besides, lower case, upper case in the names, spelling mistakes, differences of punctuation, combinations or contractions of company names, and renaming may result in retrieval failure. Thus, authority control help integrate the same assignees under one accurate patent record. Thereby researchers could avoid scanty patent of statistical data, repeated calculation of patent assignees, and so on.

The ownership classification of patent

According to the property of patent assignee, patent ownership can be divided into three types: individual, enterprise and university and research institute. Triple helix model is the main of interaction of UIG. The enterprises and universities and research institutes are the most important innovation entities and they hold a major ownership of patents. Here is one question to be noticed: How to measure the direct inventive activities of government?

The state-owned enterprise (SOE), private-owned enterprise (POE) and foreign enterprise (FE) are three main types enterprise in China. A SOE is a legal entity created by the government to undertake commercial activities on the behalf of an owner government. The Second National Economics Census in 2008 shown that 63 trillion (30% of 208 trillion) RMB—the total asset of secondary and tertiary sectors (industrial and service sectors), was held by SOEs (Xu 2010). Note SOEs here refers to state sole funded corporations and enterprises with the state as the biggest share holder. Meanwhile, in terms of enterprise number, there were 154,000 SOEs in the end of 2008, only 3.1% of the total number of enterprise. Hence, SOEs control a substantial part of total enterprise assets in China despite the fact of their marginal total number.

A POE is wholly owned by private individuals. After three decades of reform and opening up, China's POEs have experienced the profound transformation from the "need for a useful complement" to "an important component" (Ruihua 2009). At present, China's private enterprises have entered the history of the development of a vibrant new stage.

FEs in China refer to wholly foreign-owned enterprises, they are the enterprises established in China by foreign companies, enterprises, other economic organizations or individuals in accordance with Chinese law. Enterprises registered in Hong Kong, Macau, and Taiwan are considered as FEs in this study. Although it was relatively late to introduce the system to China for establishing FEs, the establishment of wholly foreign-owned enterprises has developed rapidly during recent years (Embassy of the People's Republic of China in the Republic of Iceland n.d.).

Because the aim of file patent is to ensure the right adscription of patent and protect invention in order to obtain the best economic benefit, patents owned by three types of enterprises reflect different benefits respectively. According to the definition of the three types of enterprises, SOEs are created and owned by government and stand for the benefit of government, so SOEs' patents symbolize direct technology output of government to some extents. Based on this opinion, patents of POEs and FEs reflect the direct output of technology industry. With respect to research institutes whose main task is R&D, commercial activities are sparse. It is notable that research institutes referred to in the study are independent institutions, and do not belong to enterprises. Because most of the non-profit research institutes are altogether analyzed in juxtaposition to universities. However, research organizations of enterprises are excluded in the analysis.

Results

The analysis of inventive activities and technology collaboration pattern of UIG in China is conducted. The first section deals with an overview of Chinese patents; trend shift and innovation strength are explored. The second section studies UIG's patent activities with a major focus on the distribution of patent quantity, development trend of UIG, and the distributions of innovation entities in three development phases. The third part explores patent collaboration pattern of UIG in China.

An overview of Chinese patents

The changing trend of Chinese patents

To display the overall patenting activities in China, a yearly analysis of patents issued by the USPTO is conducted. The development trend of patents in China is shown in Fig. 2.

From Fig. 2, it is obvious that China's patent numbers have upgrading unceasingly from 1976 to 2009. The number of Chinese issued patents experiences the three development phases. The first phase is 1976–1986, with very few issued patents in each year. The inventive activity of China in this period is almost could be ignored. The second phase is during 1987–1999, with a smoothly slow increase of patent numbers. The technology embryonic phase could be identified in here. The number of patent has increased rapidly from 2000. The third phase is 2000–2009 when the invention was active, especially in recent years, with an average rate of growth is as high as 36% during the period of 2006–2009.

Main innovation strength in China

In order to explore a main force of inventive activities in China, patent numbers of assignees are calculated and the top 20 patent assignees are listed. As shown in Table 1, Hon Hai Precision owns the largest issued patent, with a number of 700, followed by Hong Fu Jin Precision (586) and Sinopec Corporation (311). Both of Hon Hai Precision and

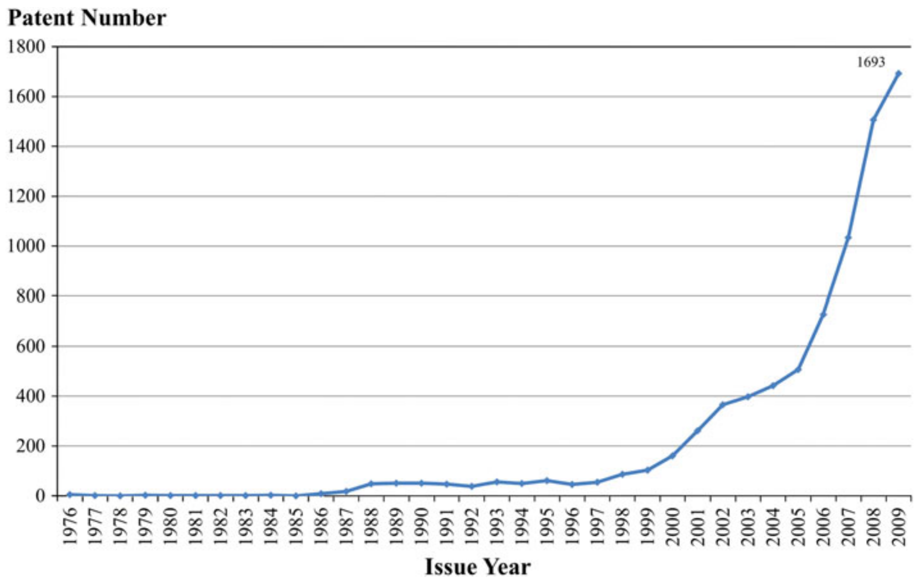

Fig. 2 Chinese patent development trend of USPTO

Hong Fu Jin Precision are Taiwanese enterprises, set up their subsidiary company in the mainland China during the 1990s, and strengthen the whole innovation ability of Chinese enterprise. The sum of patent numbers involving the top 20 assignees accounts for 3,577, and the proportion of total patents reaches to 45.6%.

The patent numbers of the top 20 assignees in recent 5 years are also calculated to show the development trend of technology. The patent numbers of these assignees have been increased rapidly, and their shares grew year by year. The share is 25% in 2005, and rises to 72.7% in 2009. The trend indicates that Chinese patent output in the US is concentrated on certain prosperous enterprises and outstanding universities.

According to the types of patent assignees, it is obvious that most of the main assignees are enterprises while two of them are universities, TsingHua University and University of Hong Kong, respectively. The POEs and FEs are the main force of innovation among these enterprises, only one enterprise is owned by government.

The inventive activities of UIG in China

Patent numbers distribution of UIG in China

Based on the types of patent assignee, the ownership distribution of Chinese patents in USPTO is analyzed and shown in Fig. 3. From the left side of figure, industry has the most inventive activities, with a 75% share of total patents, followed by university and research institute with 19% of patents, and only 5% of patents belong to government. The inventive activities of individuals are the lowest. Further research found that there are more than half of industry's patents owned by FE. The top 3 regions the FEs from are Taiwan (42%), Hong Kong (40%), and the United States (3%). It indicates that the innovation ability of SOEs is weak even if the SOEs in China create great assets. The main ownership of

Table 1 The top 20 patent assignees in China

Rank	Patent assignee	UIG	All patent numbers	Patent numbers in recent 5 years				
				2005	2006	2007	2008	2009
1	Hon Hai Precision	I	700	4	34	121	216	325
2	Hong Fu Jin Precision (ShenZhen)	I	586	0	18	101	188	279
3	Sinopec Corporation	G	311	17	19	12	44	14
4	Foxconn Technology	I	276	0	7	73	87	109
5	Fu Zhun Precision Industry (ShenZhen)	I	273	0	7	75	86	105
6	Huawei Technologies	I	192	9	18	21	50	84
7	TsingHua University	U	184	9	25	24	40	62
8	Beifa Group	I	172	20	2	28	87	57
9	SAE Magentics (H.K.)	I	119	15	20	13	25	33
10	Dong Guan Bright Yin Huey Lighting	I	110	4	0	18	17	1
11	ShenZhen Fataihong Precision	I	107	0	4	18	44	41
12	Semiconductor Manufacturing International Corporation	I	93	8	13	19	28	31
13	Sutech Trading Limited	I	83	0	3	18	43	19
14	Chervon group	I	63	12	21	10	4	5
15	Haier Group	I	60	0	0	8	2	6
16	Positec Power Tools (Suzhou)	I	60	17	19	6	2	6
17	C. C. & L Company Limited	I	50	7	5	1	1	0
18	Inncom Technology (ShenZhen)	I	49	0	0	7	20	22
19	Innolux Display Corp.	I	49	0	0	7	20	22
20	The University of Hong Kong	U	44	5	5	5	9	10
(S1) Sum of top 20 assignee			3,577	127	220	585	1,013	1,231
(T1) Total numbers of all assignee			7,841	508	728	1,034	1,507	1,693
S1 Share of T1 (%)			45.6	25	30	56.6	67.2	72.7

Chinese patents is enterprises, especially the FE. Universities and research institutes are the useful support of innovation.

Patent development trend of UIG in China

In order to explore the development trend of the patents in UIG, the yearly analysis of different types of assignees has done. As shown in Fig. 4, patent numbers are low in the former two phases, and the gap among the three types of ownership has enlarged since 2000. The patent applications of industry have increased rapidly since 2000, especially in recent 5 years. The patent numbers of university and research institute smoothly increased before 2005, and have performed in a greater way since 2006. Compared to industry and university, the patents owned by government are always lower though the patent numbers have slightly went up in recent years.

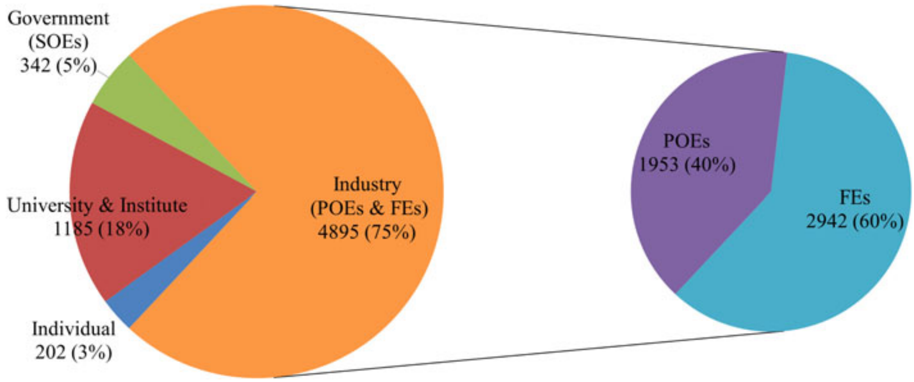

Fig. 3 Distribution of Chinese patent assignee

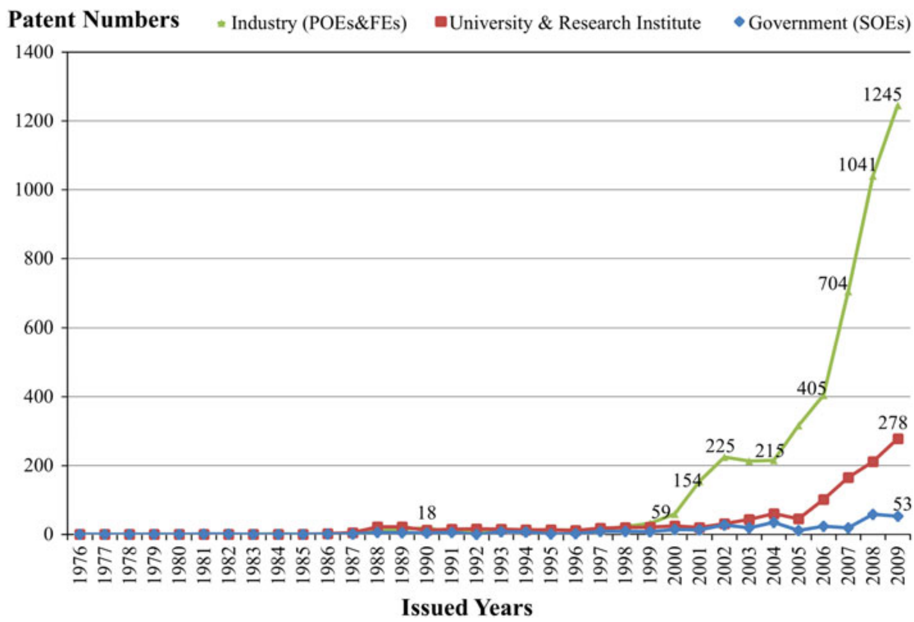

Fig. 4 1976–2009 Patent numbers of UIG in China

The patents of industry are applied by SOEs and FEs. Therefore, the development trends of SOEs and FEs are detailed analyzed. As shown in Fig. 5, all the patent numbers of FEs and POEs have increased since 2000, but the rate of growth of FEs has always been higher than the one of POEs, except 2002. According to the patent numbers in recent years, it is obvious that FEs have stronger innovation ability than POEs does in China.

The university–industry–government distribution in three development phases

UIG distributions in three development phases are also analyzed for detailed illumination. The top 10 patent assignees in three phases are listed in Table 2. It can be seen that the

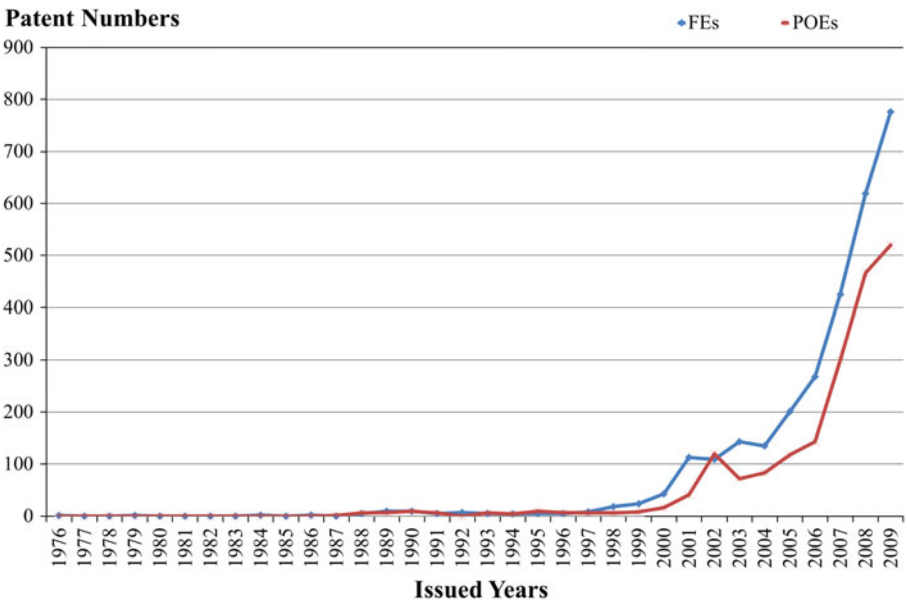

Fig. 5 1976–2009 Patent numbers of SOEs and FEs in China

distributions of UIG in three phases are different. In the first phase, there were only a few of patent numbers and patent assignees. The enterprise was the main force of inventive activities in this phase, accounted for 50% of patent assignees, especially the enterprises of Hong Kong and Taiwan. Moreover, SOEs were active entities of innovation as well. In the second phase, the numbers of patent and its assignee had risen obviously. Over half of the top 10 assignees were universities and research institutes. It shows that the universities and research institutes strengthened significantly during the period 1987–1999, became the main entity of innovation in the second phase. SOEs also played an important role in the second phase, in which Sinopec Corp. owned 69 patents. In the third phase, the numbers of patent and assignee have increased rapidly. POEs and FEs have been the main entity of innovation again, only one SOE (Sinopec Corp.) and one university (TsingHua University) are shown in the top 10 patent assignees. Compared to the top 10 assignees over the three phases, only Sinopec Corp. and TsingHua University entered the list both in the second and the third phases.

As it shown in Table 3, the first development phase, 1976–1985, there are two assignees of university, four of industry, and three of government. However, in the second development phase, 1987–1999, the number of assignees of university grows to seven, and five assignees of industry, only one assignee is from government. In the third development phase, from 2000 to 2009, there are eight assignees of industry, only one assignee belongs to government and university respectively. According to the figures discussed above, the assignees of industry have gradually risen up; however, the number of assignee of government has decreased across the three development phases.

In general, the innovation strengths in China across the three development phases have shifted from government to university and research institute and then industry. The changing process is relevant to the influence of policy and economic development.

Table 2 Top 10 UIG in three development phases

Rank	1976–1986			1987–1999			2000–2009		
	Assignee	No.	UIG	Assignee	No.	UIG	Assignee	No.	UIG
1	Formosa Plastics Corp.	2	I	Sinopec Corp.	69	G	Hon Hai Precision Industry Co., Ltd.	700	I
2	China Metallurgical Import and Export Corp.	1	G	Chinese Academy of Medical Sciences	22	U	Hong Fu Jin Precision Industry (ShenZhen) Co.	586	I
3	China National Light Industrial Products Import Export Corp.	1	G	Industrial Technology Research Institute	17	U	Foxconn Technology Co.	276	I
4	China National Seed Corp.	1	G	United Microelectronics Corp.	12	I	Fu Zhun Precision Industry (ShenZhen) Co.	273	I
5	Chung Ah Manufacturing Co.	1	I	Bayer AG	11	I	Sinopec Corp.	242	G
6	Institute of Zoology Academia Sinica	1	U	TsingHua University	11	U	Huawei Technologies Co.	192	I
7	Nianbilla Co.	1	I	Acer Inc.	8	I	TsingHua University	173	U
8	North China Research Institute of Electro-Optics	1	U	Tianjin University	7	U	Beifa Group	172	I
9	Paul Wurth S.A.	1	I	Winbond Electronics Corp.	6	I	SAE Magentics (H.K.) Ltd.	119	I
10	–	–	–	Donguan Juguan Metal Lighting Factory Co.	4	I	Dong Guan Bright Yin Huey Lighting Co.	110	I
	–	–	–	Fujian Institute of Research on the Structure of Matter, Chinese Academy of Sciences	4	U			
	–	–	–	Peking University	4	U			
	–	–	–	Shanghai Institute for Biochemistry, Chinese Academy of Sciences	4	U			

Table 3 Distribution of top 10 UIG in three development phases

	1976–1986	1987–1999	2000–2009
University (U)	2	7	1
Industry (I)	4	5	8
Government (G)	3	1	1
Total	9	13	10

Though the Opening-up Policy has been adopted since 1978, the process of implementation needs to be examined step by step in the initial stages. SOE is still the main agent of commercial activities in the first development phase. The innovation model is like Triple Helix I, where government plays a dominant role and the innovation capacity remains weak. Patent output was few, and SOEs have played an important role in inventive activities. In the second phase, development of technology through science education appeared in China in 1986. Many programs of science and technology have emerged. For instance, the National High Technology Research and Development Program (with a figure of 863 projects) was issued in 1987, aiming to promote the development of high technology in China. Another project, "National Torch Program" has been implemented since 1988 in order to push the commercialism, industrialization and internationalization of scientific and technological achievements. At the same time, the economic development provided the momentum to transform technology into product. Universities and research institutes were encouraged to participate in commercial activities under such atmosphere. Patent applications from universities and research institutes increased significantly. In the third phase, following the successful implementation of Opening-up Policy, the economy and science and technology of China have grown rapidly. POEs and FEs have developed rapidly over recent 10 years and become the main economy strength in China. The innovation capacity of POEs and FEs has expanded greatly and surpassed that of universities and research institutes and SOEs.

Patent collaboration of UIG in China

Patent assignee numbers distribution

Based on the number of patent assignee in each patent, the assignee distribution of Chinese patents issued by USPTO is analyzed and the result is shown in Fig. 6. According to Fig. 6, patents with single assignee stand for 71% whereas patents with multiple assignees account for 29% in the chart. Further, patents with multiple assignees mainly belong to two-assignee patents. From the distribution of patent assignees shown, we could infer that 29% of the Chinese patents issued by USPTO were output by technology collaboration.

The collaboration of UIG in China

The collaboration among UIG fuels the innovation drive of a country. In order to explore the collaboration pattern of UIG in China, the co-patent numbers are calculated.

The collaboration between university and government There are 38 co-patents of university and government, and the yearly distribution of co-patent can be seen in Fig. 7. The first co-patents appeared in 1988; only few of yearly co-patent numbers can be seen, and

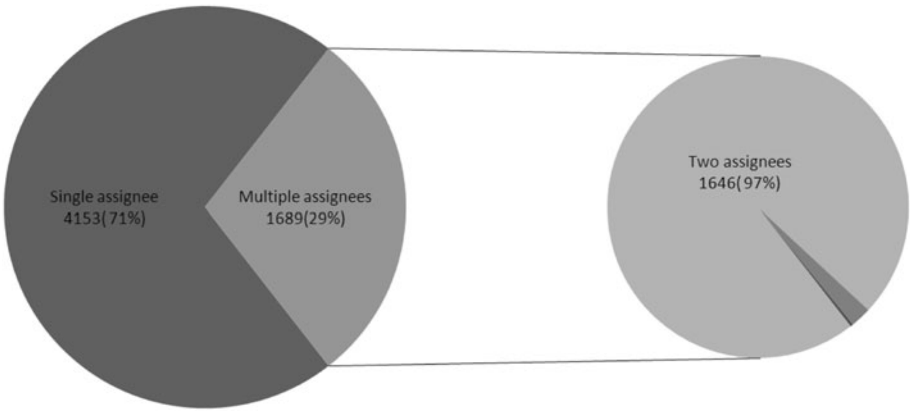

Fig. 6 Chinese patent assignee numbers distribution

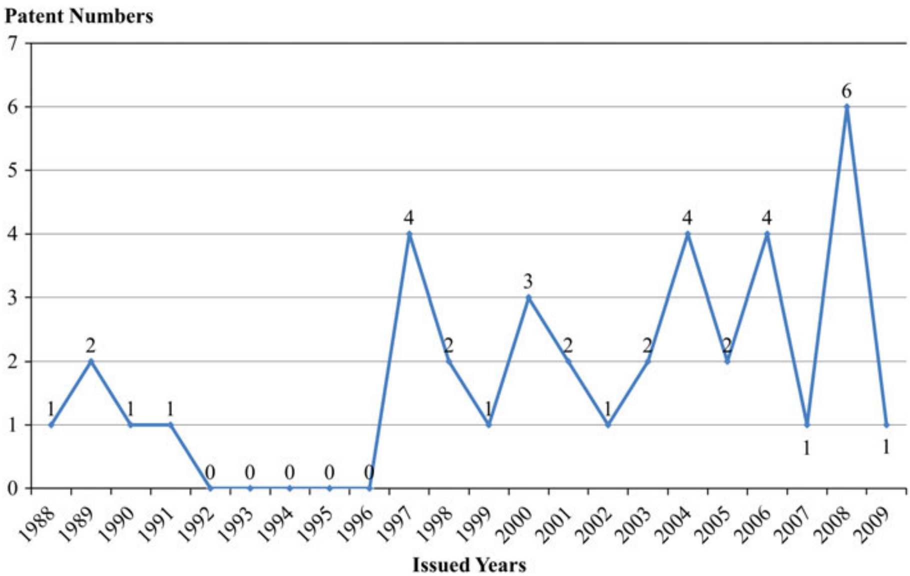

Fig. 7 The collaboration status between university and government in China

the largest number, 6, is shown in 2008. It indicates that the trend of direct inventive collaborations between university and government in China is less frequent.

The collaboration between industry and government There are only 14 co-patents of industry and government. The yearly distribution of co-patent can be seen in Fig. 8. The first co-patent was shown in 1986. There was no co-patent in most of the later years, and the largest co-patent number is 2. It indicates that the direct inventive collaborations between industry and government in China have always been insufficient.

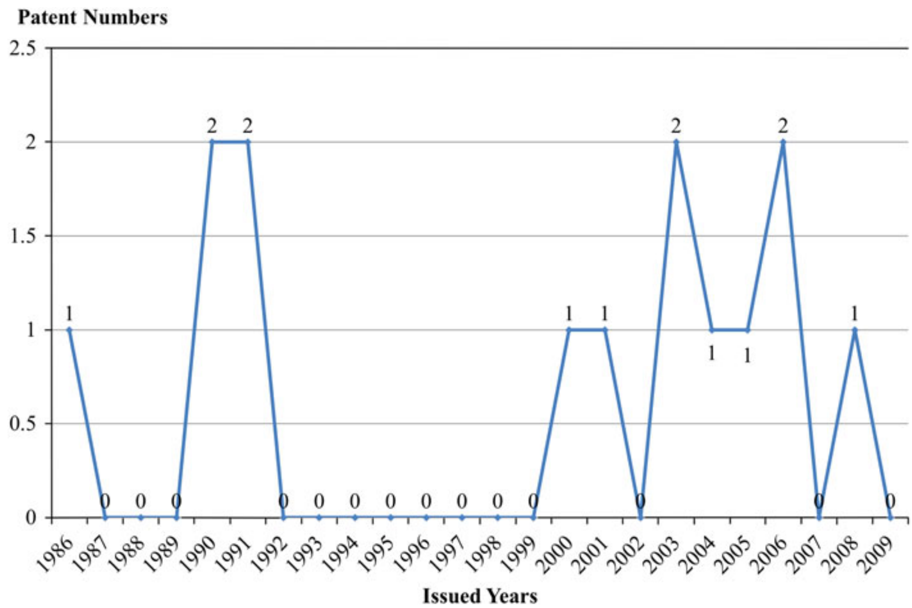

Fig. 8 The collaboration status between industry and government in China

The collaboration between industry and university There are 499 co-patents applied by industry and university. The figure is bigger than that of co-patent in industry and government. The yearly collaboration distribution can be seen in Fig. 9. There were few co-patents before 2005, but the number has rapidly went up in the recent 4 years. There were only 10 co-patents in 2005, while 173 co-patents in 2009, showing a rapidly increasing trend of collaboration between industry and university.

The patents of industry are applied by POEs and FEs. Since the co-patent number is too large, the collaboration status between POEs and universities, the collaboration status between FEs and universities and research institutes are analyzed respectively. There are 425 co-patents applied by FEs and universities and research institutes. The figure is much bigger than the one of POEs and universities and research institutes. According to Fig. 9, the increase of co-patent numbers in recent years is mainly due to the collaboration between FEs and universities and research institutes.

Models of UIG relationship in China According to the research results of inventive activities and collaboration status of UIG in China presented in the previous two sections, the UIG model in China is described in Fig. 10. The model is close to the Triple Helix III drawn in Fig. 1. It can be seen from Fig. 10 that the industry sphere has the strongest innovation capacity in China, followed by university and research institute. The innovation capacity of SOE appears relatively weak. In respect of collaboration status, only a few of collaboration between industries and universities exists in the SOEs. Though the collaboration between industries and universities has increased in recent years, the tripartite patent-wise collaboration among UIG are almost ignored. Scarce co-patents collaborated by SOEs, universities, and industries indicate that the technologically inventive activities among government, universities and industries in China is insufficient. It might represent

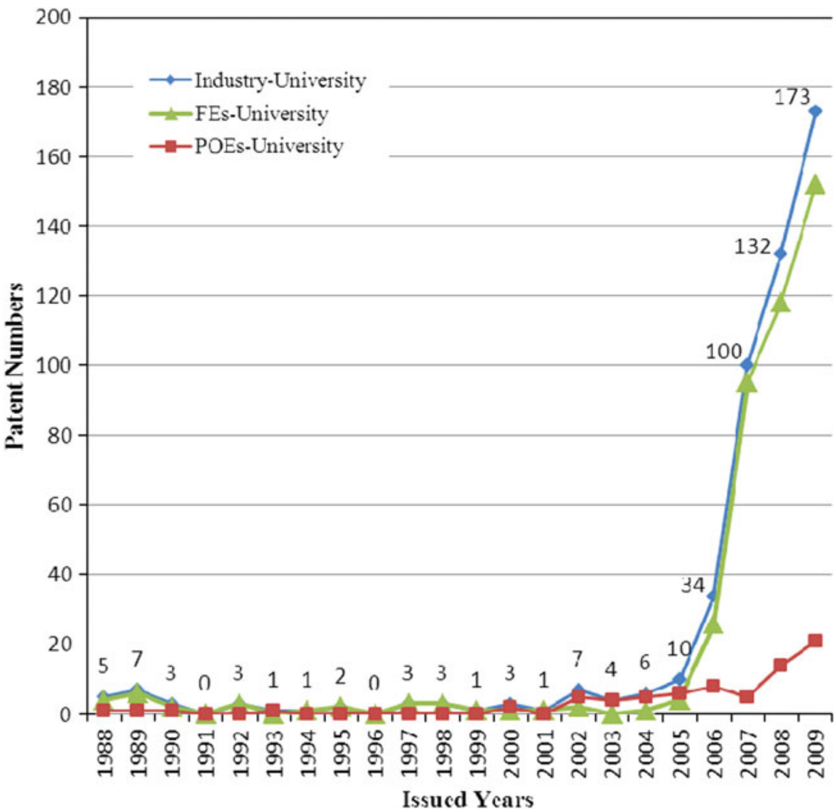

Fig. 9 The collaboration status between industry and university in China

imperfect innovation relations of UIG in China. The invention collaborations of UIG in China need to be strengthened in the future.

In order to explore the evolution of innovation systems in China, UIG relation models in three development phases are drawn in Fig. 11. There are only four co-patents applied by university, industry and government, which indicates that the tripartite collaboration of patent is very difficult in China. The innovation models have also experienced the shift from etatistic model towards improved “laissez-faire” model and then triple helix model. In the first development phase, the government played an essential role. Innovation was discouraged, without any collaboration among UIG. This case is consistent with the etatistic model, like the former Soviet Union and the Eastern European countries under the ideology “existing socialism”. In the second development phase, with the influence of policy and the projects of science and technology, the innovation system has gradually changed. University and research institute and surpassing enterprises have begun to play an essential role of the innovation activities in knowledge-based societies. Though the numbers of co-patents were small, the collaborations among UIG have begun shown up. This case is similar to “laissez-faire” model yet not the same one. The innovation units were neither absolutely independent from the institutional spheres nor trilaterally overlapped. Nevertheless, this mode also had features of highly circumscribed relations among the spheres like “laissez-faire” model. Therefore it can be considered as an improved “laissez-faire” model. In the third development phases, industry has turned into a unit of strong innovation ability in

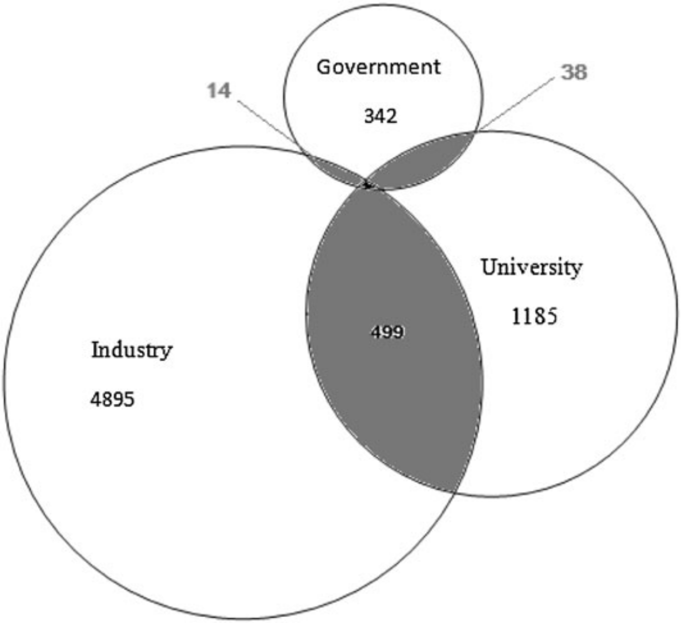

Fig. 10 The global UIG model of in China

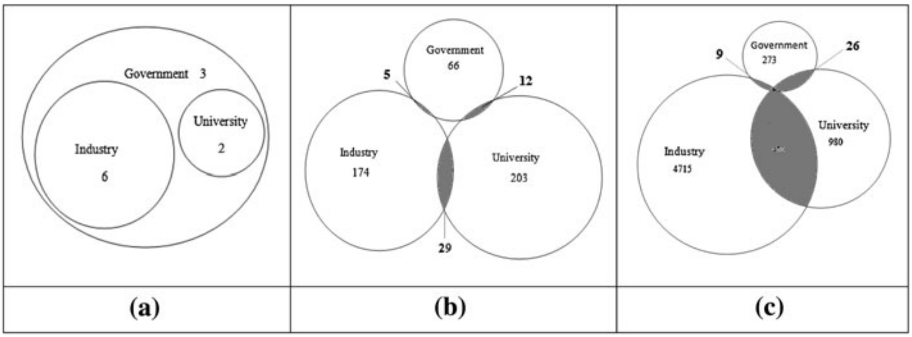

Fig. 11 The UIG models in China of three development phases. **a** UIG relation model in the first phase (1976–1986), **b** UIG relation model in the second phase (1987–1999) and **c** UIG relation model in the third phase (2000–2009)

China, and the collaborations between industry and university have grown rapidly. The UIG relations of this phase are close to the Triple Helix III model that is trying to attain some form of developed countries and regions, especially the United States.

Conclusion

This study is intended to examine the inventive activities and collaboration patterns of UIG in China from patent analysis. Through the analysis of Chinese patents which are issued in the United States, the research herein has drawn the following conclusions.

China's patents have quantitatively upgraded from 1976 to 2009. The number of Chinese patents has experienced three developmental phases. The first phase is 1976–1986, with very few issued patents in each year. The second phase is 1987–1999, with a smoothly slow increase of patent numbers. The third phase is 2000-2009, with a rapid increase of patents, especially in recent 5 years.

According to the top 20 selected assignees in China, most of the main assignees are enterprises. The rest are two universities, TsingHua University and The University of Hong Kong. Hon Hai Precision owns the largest issued patent number, followed by Hong Fu Jin Precision and Sinopec Corporation. The patents of these assignees have increased rapidly in recent 5 years. The trend shows that Chinese patent output in the U.S. is primarily contributed by several specific prosperous enterprises and universities.

Ownership-wise, the industry (POEs and FEs) is the main force of inventive activities in China, sharing 75% of total patents. The universities and research institutes are also supporting to apply patents. However, the innovation ability of government (SOE) is weak. The gap of inventive activities among UIG has deepened since 2000, especially in recent 5 years. The quantity of patents in recent years obviously indicates that FEs have stronger innovation ability than POEs do in China.

In a more detailed study, the UIG configurations in three development phases were analyzed. It is clear that the innovation strengths of China in three development phases have experienced the shift from government to university and research institute to industry. The innovation models have also experienced the shift from etatistic model towards improved "laissez-faire" model, and then triple helix model. The global UIG model in China was also explicated. According to the number of assignee in each patent, distribution of Chinese patents in USPTO is analyzed. 71% patents have only one assignee; patents with multiple assignees occupy 29% of all patens. Most of co-patents have two assignees. The collaboration between university and industry has improved during recent years, but the other forms of collaborations among UIG are weak and should be reinforced in the future. According to the research results of Chinese inventive activities and collaboration status of UIG, the UIG model in China is close to Triple Helix III. But the collaboration relationship of government, universities and industries in China is insufficient. The current Chinese UIG model is not perfect.

In conclusion, the study, with the help of patent analysis, explores Chinese inventive activities and technology collaboration patterns of UIG in the prospect of providing a reference for the directions of future policy and academic researches. Three innovation characteristics of UIG in China can be featured: First, FEs are the strongest innovation unit in China, and these enterprises are most from Taiwan and Hong Kong. Ignoring the innovative capacities from these two regions will leave FEs occupy only a few percentage of inventive outputs, and POEs will top the rank. Second, collaborations between industry and university grow rapidly. The trend helps to promote a positive innovation system. Last but not least, the Chinese UIG relations are close to Triple Helix III, though the collaborations of UIG still need to be encouraged and strengthened in the future.

Although the researchers of this study attempt to measure Chinese inventive activities and the patterns of technology collaboration of UIG by the statistics of patent, several issues need to be addressed. First of all, patent document is only one type of outputs of innovation activities, and the research results are inevitably limited by the information provided by patents. Secondly, patent count fails to measure the quality of individual patent as each has its own different value. Future studies should embrace a well-designed indicator of patent analysis from the perspective of both quantity and quality of patents. That way, measurement with tighter accuracy may be possible. In addition, factors like the citing and cited patterns, the legal statuses, and the technology classifications should be taken into consideration. A recommended solution is to gather further information from research paper, economic and R&D investment data. Adding the information to current patent analysis might help establish a more reliable system.

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