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An analysis of the patenting activities and collaboration among industry-university-research institutes in the Chinese ICT sector

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Abstract Few comprehensive and long time-span studies have examined the Information and Communication Technologies (ICT) sector in China and its implications for China's national and regional innovation system. Taking advantage of the patents granted by the State Intellectual Property Office of the People's Republic of China from 1985 to 2010, this paper examined innovation performance in the Chinese ICT industry with the help of bibliometric techniques. The analysis has been conducted from several perspectives, including the trend and character of patent outputs, the most prolific Chinese regions and their changes, the primary innovators and their type of institutions, and the collaboration among university (U)-industry (I)-research institutes (R). The results show that the great importance that the government and domestic enterprises attach to technology R&D and patent protection has brought significant improvements in the Chinese ICT sector, and enterprises have thus gradually become the main body of technological innovation in recent years. In terms of U-I-R collaborations, I-I collaborations are the most popular pattern, followed by U-I and I-R collaborations. In the last 20 years or so, U-I-R collaborations have improved, but they are still weak. In the future, U-I-R collaborations should be further reinforced, and more universities and research institutes should be encouraged to become involved in U-I-R collaborations to help enterprises enhance their innovative capabilities.

Keywords Patent · Collaboration · Industry-university-research institute · ICT

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Introduction

The rapid diffusions of the Internet, mobile telephony and broadband networks all demonstrate how pervasive Information and Communication Technologies (ICT) have become. ICT have been at the heart of economic changes for over a decade. It is critical to improve the competitiveness of all industrial sectors and meet the demands of society and the economy. Being at the leading edge of development and innovation in this type of technology has always been an objective for governments. The EU Member States have earmarked a total of €9.1 billion for funding ICT over the duration of the EU's Seventh Framework Program (FP7)to improve the competitiveness of European industry.[1] The United States has invested over $3 billion to master and shape the future development of these technologies under the Federal Networking and Information Technology R&D Program (NITRD) (ITStrategy Research Group 2009).

As an emerging country, China is by far the largest exporter of ICT goods, and it is now the largest importer (OECD 2010). An important challenge for the Chinese government is how to seize greater benefits from ICT for economic growth and development. In fact, the ICT industry is recognized as being among the high-technology industries in the National High-Tech R&D Program of China (863 Program) launched by the Chinese government as far back as 1986. The central government allocated 33 billion RMB in total to the 863 Program from 1986 to 2005. In the 11th Five-Year Plan (2006–2010) period, there was a significant increase in ICT investment in several key areas, including web and mobile technologies, information acquisition and processing technologies, and information security technologies. In 2009, China considered the ICT industry to be a national strategic and emerging industry, and this industry became an important force to promote economic recovery. The goal of the national program for medium- to long-term scientific and technological development (2006–2020) is to turn China into a major player in the ICT industry by 2020. Because of the significance of the ICT sector for the economy and its social impact, policy makers are increasingly demanding indicators to measure the effect of the government's ICT policies.

In pace with the investment increase from the Chinese central government, the capacity for independent innovation in ICT industry has improved, and the innovation output has increased rapidly. The number of ICT patents has risen strongly in China over the last 10 years. China (4.2 %) was among the top five countries, with over 2000 ICT-related patents under the PCT in 2005 (OECD 2008). China had a large concentration of ICT-related patents compared to all countries, as depicted in the revealed technological advantage index. With an index value of 1.42, China's revealed technological advantage ranked third in 2003–2005, after Finland and Singapore (OECD 2008). However, the ICT industry in China falls behind many other advanced countries as a whole. Over several decades, dozens of major technical innovations, such as the Internet, Web Explorer and Linux, appeared in this field, but none of them were invented by Chinese researchers. Publications in top journals are also few, and the international visibility of publications from China is still low. To become a major player in the ICT industry by 2020, China needs to significantly boost its R&D efforts and promote university-industry-research institutes (U-I-R) collaboration to realize strong technological leapfrogging. It is therefore meaningful to analyze technological performance in the Chinese ICT industry, as reflected by its patenting activities, and to investigate the character of U-I-R collaboration.

[1] http://cordis.europa.eu/fp7/ict/.

Over the past few years, innovation studies and related fields have placed considerable emphasis on a systemic view. Firms are usually considered to have a leading role in innovation, and the university is considered a supportive structure for innovation, providing trained persons, research results, and knowledge to the industry, while the role of the government is not only to control and regulate, but also to support cooperation between the university and industry (Lei et al. 2012; Liang et al. 2012). Typically, the dynamics of the reciprocal university-industry-government (U-I-G) relationships in the commercialization of new knowledge has been described by the "Triple Helix Model"(Etzkowitz and Leydesdorff 1995, 2000). This model has been used to investigate the relationship among university, industry and government in such nations as Sweden, South Korea, the Netherlands, the United States, and Canada (Danell and Persson 2003; Park et al. 2005; Park and Leydesdorff 2010; Leydesdorff and Meyer 2010; Belkhodja and Landry 2007).

However, China's national innovation system has undergone profound economic and organizational reforms from a central resource allocation planning system to a free market mechanism. The U-I-G relationship in China is different from that in western countries. For example, in the United States, the university plays a key role in U-I-G collaboration. A total of 80 % of basic research jobs and 28 % of applied research jobs across the United States have been taken by colleges and universities. Universities and the government have close relationships, and collaborations between universities and industry are very active. The government and industry are the main funding sources for the universities. Government intervention is relatively weak in the collaborations between universities and industry. The case in China is different. In China, universities and research institutes have played a leading role in innovation for a very long time, and firms are becoming the main source of technological innovation due to the reforms in the science and technology system in recent years. The Chinese government primarily exerts its function through policy, planning, and funding. In fact, China's science and technology policies place more emphasis on the importance of cooperation between industry-university-research institutes to enhance national innovation ability. In the past two decades, the Chinese government has continuously promoted cooperation among enterprises, universities and research institutes. A total of 332 laws or government regulations aiming to strengthen cooperation among enterprises, universities and research institutes have been stipulated by the State Council of China or established by the agencies of the central government between 1992 and 2007[2] (Liang et al. 2012). It is more meaningful to investigate the relationship among industry-university-research institutes (U-I-R) than among U-I-G in China.

The contributions of the government to the triple helix of university-industry-government are always difficult to quantify, so few studies have been conducted on the U-I-G relationship for China. Based on the Triple Helix Model, Lei et al. (2012) examine the inventive activities and the relationships among U-I-G in considered China. In their work, state-owned enterprises (SOE) are to represent the government in the U-I-G relationship. The Chinese government is the controlling shareholder of SOEs, but the operations of SOEs follow market rules, just as private businesses do. Therefore, SOEs should be recognized as industry and not government in the U-I-G relationship. Additionally, few studies have been conducted on the relationship of U-I-R to date (Chen and Guan 2011). Many academics study only cooperation between universities and industry in the Chinese innovation system (Liang et al. 2012). In these studies, public research institutes are analyzed in juxtaposition to universities or are excluded from the analysis. Public research institutions play an equally important role to the universities in innovation. For example, in

[2] http://www.lawinfochina.com/.

the Chinese biotechnology field, patent inventions have been primarily conducted by public research institutes (Chen and Guan 2011). The research institutes of the Chinese Academy of Sciences (CAS) are the primary innovators and conduct major scientific and technological projects. A split between university and research institutes would thus be more informative than lumping the two together in a U-I-R analysis.

Bibliometric analysis is widely used to evaluate the developmental state of the science and technology fields (Chen and Guan 2011; Guan and Gao 2008; Rojo and Gómez 2006), while it is rare to explicitly consider the ICT sector as a whole. Some studies have used bibliometric tools to examine a specific field: Computer Science (Guan and Ma 2004), Semiconductors (Tsay and Ma 2003), and Telecommunications or Consumer Electronics (Gao and Guan 2009a). There are other general studies on innovative activity based on patents, including ICT (Hicks et al. 2001). One recent study on the ICT sector as a whole is the work of Rojo and Gómez (2006). These authors use a bibliometric analysis to present a general view of the scientific and technological production in the ICT sector in Spain based on paper and patent data, respectively. In the case of China, there are two studies on technology correlation in the ICT sector based on International Patent Classification (IPC) (Lei and Chen 2011; Liu et al. 2010). However, comprehensive and long time-span studies on the ICT sector in China have seldom been conducted.

The aim of the present study is to analyze the technological innovation performance and collaborations of industry-university-research institutes in the Chinese ICT industry, as reflected by patenting activities based on the State Intellectual Property Office of the People's Republic of China (SIPO) database during 1985-2010. In particular, this study focuses on the following issues: (1) Analyzing the trends and characteristics of patenting activities in each sub-domain of the ICT industry during different periods, i.e., the number of patents or the distribution of patent types;(2) Identifying the most prolific Chinese regions and their changes, i.e., the leading regions in the Chinese ICT industry and how the spatial distribution change in different time periods; (3) Identifying the most prolific organizations and their types of institutions, i.e., the leading performers in the Chinese ICT industry and where they come from (i.e., universities, industry, or research institutes),particularly how the leading performers vary with the changes in science and technology policies in different time periods; and (4) Exploring the collaboration patterns and their changes, i.e., whether industry (I), university (U) and research institutes[3] (R) collaborate with others, which collaboration patterns they prefer (i.e., U-I, U-R, I-R, U-U), and how collaboration patterns change in different sub-domains over different time periods.

Data and methods

Patents provide a valuable source of information on technology development and innovative activity. Due to the high patent quality and high data quality of U.S. patent statistics (Chen and Guan 2011; Lei et al. 2012) compared to the Chinese database, most studies on China use patent data from the United States Patent and Trademark Office (USPTO) to measure the technological innovation in a particular technology field (Gao and Guan 2009b; Guan and Chen 2012; Lei et al. 2012). However, it is worth noting that only a small percentage of the total Chinese patents came from the USPTO, while most of the Chinese

[3] Research institutions refer to public research institutions, and the research organizations of enterprises are excluded.

Table 1 International patent classification codes selected for ICT sector

ICT domains	IPC codes
Telecommunications	G01S; G08C; G09C; H01P; H01Q; H01S; H1S5; H03B; H03C; H03D; H03H; H03M; H04B; H04J; H04K; H04L; H04M; H04Q.
Consumer electronics	G11B; H03F; H03G; H03J; H04H; H04 N; H04R; H04S.
Computer, office machinery	B07C; B41J; B41K; G02F; G03G; G05F; G06; G07; G09G; G10L; G11C; H03K; H03L
Other ICT	G01B; G01C; G01D; G01F; G01G; G01H; G01J; G01K; G01L; G01M; G01N; G01P; G01R; G01V; G01W; G02B6; G05B; G08G; G09B; H01B11; H01J; H01L

patents were granted by the SIPO. From 1976 to 2010, there were only just over 8,000 Chinese patents granted in the USPTO (Lei et al. 2012). From 1985 to 2010, the number of Chinese patents granted in the SIPO reaches over 3.3 million.[4] This extensive patent information provides a record of innovation at the individual, organization, regional and national levels in a particular technology field at the same time, and it can be efficiently used to map the technological activities at various levels (Chen and Guan 2011). However, the data from the USPTO are more accessible and more easily transferred into an analyzable form than the original data form (.txt) from the SIPO, so the patent data from the SIPO are not widely used in studies of technology development and innovative activity in China. With the improvement of the SIPO database, the data from the SIPO have become more accessible and easier to manage. In this paper, the Chinese ICT patent data were retrieved from the SIPO using the Patent Information Analysis System[5] .

According to the OECD criteria (OECD 2008), patents taken in the ICT sector can be split into four fields: Telecommunications (A), Consumer Electronics (B), Computer &Office Machinery (C), and Other ICT (D), based on the following list of International Patent Classification (IPC) codes (Table 1). To search the Chinese ICT patents granted by the SIPO, Chinese regions have been chosen in the field of assignee country and regions. Finally, a total of 450,585 Chinese ICT patents from the four fields during the period 1985–2010 were retrieved from the SIPO. Every record includes the patent number, inventor name, assignee name, assignee country and region, applicant year, and IPC code. There are problems in identifying assignees, which are caused by inconsistent spelling, acquisitions, and parent companies and their subsidiaries. In this paper, the patents of the acquired assignees after acquisitions have been assigned to the acquiring companies and the patents of the subsidiaries have been incorporated to their parent companies, as in previous studies (Hanaki et al. 2010; Chen and Guan 2011).

In addition, to clarify the changes in technological performance and the dynamics of U-I-R collaborations in the Chinese ICT industry, we split the sample into three periods: 1985–1994, 1995–2005 and 2006–2010. The first two phases have an equal length, i.e., 10 years, while the time interval of the third phase is 5 years. Several reforms in science and technology policy have been witnessed since the mid-1980s. In 1985, the Chinese patent law was enacted, and the structural reform of the science and technology system also began. From 1986 to 1993, government research funding decreased at an annual rate of 5 %. Universities began to establish their own enterprises at that time, and industry

[4] http://www.sipo.gov.cn/tjxx/.

[5] The software developed by the SIPO was purchased for downloading the patent data. The downloaded data are more accessible and easily transferred into an analyzable form.

funding became the most important source of research funding for universities (Hong 2008). In 1994, a national forum encouraged institutional mergers and decentralization for efficiency purposes (Yang 2000). The decentralization reform had the implication of promoting U-I-R collaborations. Since the 1995 National Scientific Meeting, the Chinese government has further promoted collaborations within or among universities, research institutions, and industries. In addition, the issue of the "Chinese Bayh-Dole Act" in 1999 and the second amendment of the Chinese patent law in 2000 have induced a huge increase in the number of patents from universities and industry. In particular, with the 2006 National Scientific Meeting and the implementation of the national program for medium- to long-term scientific and technological development (2006–2020), the Chinese government has further stimulated innovation activities and institutional reforms, strengthened independent innovation capability, and deepened U-I-R collaborations. Therefore, the number of patents and the intensity of U-I-R collaborations are expected to be dramatically high in the third period, although this period covers only 5 years.

Results

An overview of Chinese ICT patent activities

With the rapid development of the Chinese economy, technological innovation is becoming increasingly active, and the patent numbers have maintained rapid growth. From 1985 to 2010, the number of Chinese ICT patents granted by the SIPO has reached approximately 4.5 million, including over 2.6 million invention-type patents. From 1985 to 2000, the number of patents in the ICT sector increased slowly, and since the beginning of the twenty first century, the number has grown rapidly, with an annual increase of over 30 % (Fig. 1).

The growth trend in the patent numbers from the four fields, i.e., Telecommunications, Consumer Electronics, Computer& Office Machinery, and Other ICT, also holds from 1985 to 2010 (Fig. 1). Examining Figs. 1 and 2, the patents in Other ICT show the fastest growth rate, accounting for approximately 36 % of the total Chinese ICT patents, followed by those in Computer and Office Machinery, which account for approximately 26 %.

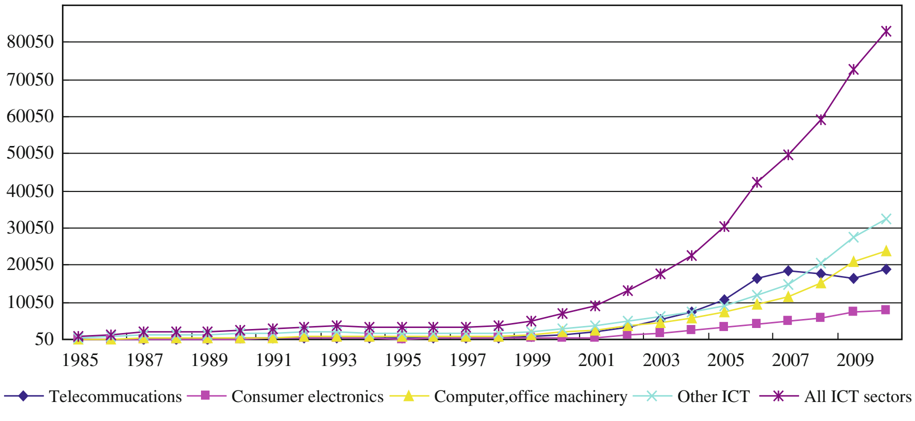
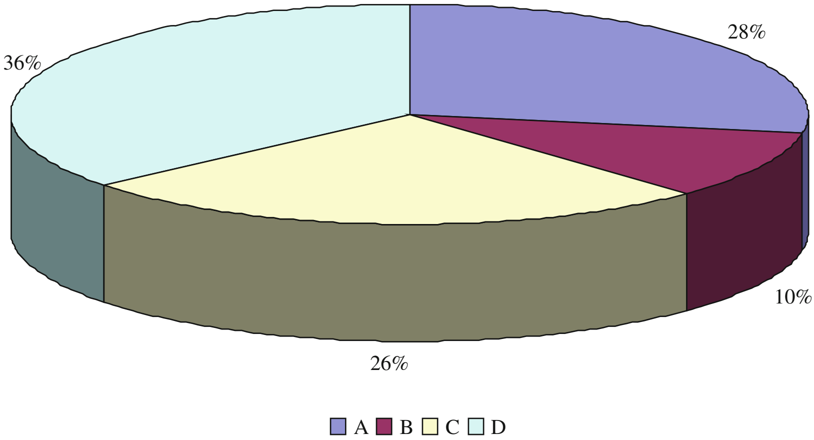


Fig. 1 The number of patents in each domain for each year



A=Telecommunications; B=Consumer electronics; C=Computer & office machinery; D=Other ICT

Fig. 2 The percentage of total patents in each domain

Telecommunications growing until the end of 2007, when the first decline appeared and lasted for the following 2 years, with growth resuming in 2010. The international financial crisis might be part of the reason for this fluctuation.

Table 2 shows the total ICT output in China by domains and periods. The number in the first bracket of the cell denotes the ratio of patents from a given domain in a given period to the total patents in this period. The number in the second bracket of the cell represents the ratio of patents from a given period in a given domain to the total patents in this domain.

In period one, each domain has only thousands of patents, which is a relatively small number. In period two, the quantity has increased dramatically to tens of thousands of patents in each domain. In addition, in the shorter period three, which covers only 5 years, the number of patents in each domain exceeds the total for the first two periods, accounting for over two-thirds of the total patents in each domain (Table 2). Compared with the percentage in the first bracket of each column in each domain, the table shows that outputs in domain D (Other ICT) occupy the largest share of the total patents in each period. Furthermore, some changes have been found in the structure of Chinese ICT patents from 1985 to 2010. The patents in domain D (58 %) account for over half of the total in period one, while in the last two periods, this percentage drops to approximately 35 %. Meanwhile, the share of patents in domain A has grown dramatically, from 12.6 % in period one to 30 % in the last two periods.

As shown in Fig. 3, invention-type patents represent 58 % of the total for all Chinese ICT patents, 76 % for Telecommunications, 64 % for Computer& Office Machinery, 53 % for Consumer Electronics, and 42 % for Other ICT. Compared with the other domains, the patents in Telecommunications and Computer& Office Machinery require a higher technological level, so the invention-type patents in these domains account for a larger proportion of the total. Due to the lower technology required for Other ICT, the utility-type patents have a higher percentage in the total for this category.

Invention-type patents have a higher technological value and are often used to measure the level of technological innovation. Figure 4 shows the changes in invention-type patents at different periods. Generally, the proportion of invention-type patents in the total has

Table 2 The output of Chinese ICT patents by domain and period

Periods	Domains				$\sum i\cdot$
	A	B	C	D	
1985–1994	3,136 (12.6 %) (2.5 %)	2,160 (8.7 %) (4.9 %)	5,184 (20.8 %) (4.4 %)	14,470 (58 %) (8.8 %)	24,950
1995–2005	33,129 (28 %) (26.5 %)	11,459 (9.7 %) (26 %)	30,722 (25.9 %) (26.3 %)	43,199 (36.5 %) (26.2 %)	118,509
2006–2010	88,629 (28.9 %) (71 %)	30,462 (9.9 %) (69.1 %)	80,968 (26.4 %) (69.3)	107,067 (34.9 %) (65 %)	307,126
$\sum \cdot j$	124,894	44,081	116,874	164,736	450,585

A telecommunications, *B* consumer electronics, *C* computer, office machinery, *D* other ICT

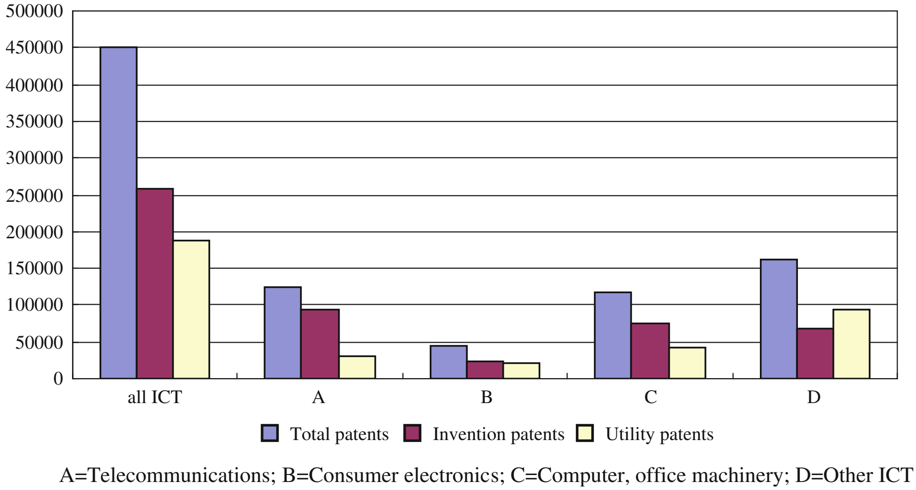


Fig. 3 The ICT patents for each domain by patent type

increased over the past three periods. In period one, the invention-type patents only account for 35 % of the total, 52 % in period two, and 63 % in period three. These data show that with the reform of the science and technology system, the technological innovation capability in the Chinese ICT sector has improved.

Performance of the Chinese regions in the ICT sector

In the previous section, we obtained an overview of the Chinese ICT patent activities. In this section, we focus on the performance of the Chinese regions and their changes in each domain at each period in the ICT sector.

The analysis of the regional origin of the ICT patents shows a strong concentration in three regions: Guangdong, Beijing, and Shanghai (shown in bold in Table 3). The three regions are the most powerful regions in terms of the number of patents obtained from 1985 to 2010, sharing over 50 % of the total Chinese patents in the ICT sector. These

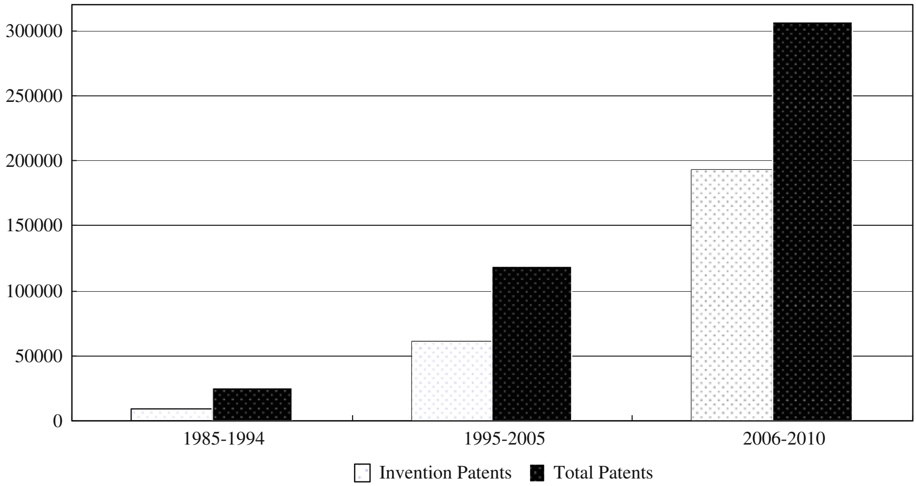


Fig. 4 The ICT patents by patent type for each period

regions bring together a large number of excellent universities, research institutes, ICT-related companies and industry clusters, which all play an important role in patent production. However, for the past 25 years, the number of patents in the less developed provinces, such as Neimenggu, Hainan, Ningxia, Qinghai and Xiang, has been much lower than the number in those developed regions. In addition, the specialization of regions can be observed by domain: Guangdong in Telecommunications (A), Consumer Electronics (B), and Computer& Office Machinery (C), followed by Beijing and Shanghai.

Table 4 presents the number of patents by region in each domain for the three periods, and the top 5 are marked by bold values. In period one, the number of patents in the regions at each domain is much lower, and this number has a large increase in the following two periods. In particular, the dramatic increase in patents during the short third period has been remarkable to witness. The number of patents in each domain for such economically developed provinces as Beijing, Guangdong, Shanghai, and Jiangsu has surged during periods two and three. However, for those less developed provinces, i.e., Hainan, Ningxia, Qinghai, Xinjiang, and Xizang, the volume is still low and has increased slowly over the three periods. In addition, Beijing, Guangdong, Jiangsu and Shanghai have maintained their positions as the top players in each domain for the three periods. It is worth noting that the number of patents for Liaoning province was one of the top five for domains A, C and D at period one, but it was flat for the following two periods.

Performance of U-I-R and their collaborations

To explore the leading performers of the Chinese ICT industry and their changes over different time periods, the patents of assignees were calculated, and the top 10 patent assignees are listed.

As shown in Table 5, in period one, Tsinghua University owned the largest number of patents, with a total of 229, followed by Zhejiang University (160) and Southeast University (113). During this period, 8 of the 10 top players came from universities, and outstanding universities were the main force behind inventive activities. However, with the deepening of the reform in the science and technology systems during periods two and

Table 3 The number of patents in the Chinese regions in each domain (1985–2010)

Region	Total	A	B	C	D	Region	Total	A	B	C	D
Guangdong	119,850	53,592	18,078	31,292	16,888	Anhui	5,857	949	444	1,037	3,427
Beijing	76,890	23,344	8,139	24,326	21,081	Chongqing	5,129	822	344	1,030	2,933
Shanghai	47,483	10,846	6,465	12,896	17,276	Jilin	4,940	586	408	773	3,173
Jiangsu	38,645	6,943	4,093	8,936	18,673	Jiangxi	2,705	348	269	852	1,236
Zhejiang	29,458	6,143	3,219	6,314	13,782	Shanxi	2,609	298	283	513	1,515
Shandong	22,409	2,854	3,482	5,099	10,974	Guangxi	2,061	279	293	495	994
Sichuan	13,757	3,269	2,213	3,333	4,942	Yunnan	2,052	175	185	486	1,206
Liaoning	13,386	1,570	1,793	2,619	7,404	Gansu	1,477	120	88	235	1,034
Hubei	12,295	2,521	1,123	2,453	6,198	Guizhou	1,312	145	257	309	601
Shaanxi	11,979	2,349	999	2,747	5,884	Xinjiang	1,096	100	151	242	603
Tianjin	10,431	1,382	1,636	2,080	5,333	Neimenggu	986	107	122	237	520
Fujian	9,126	2,163	1,294	2,539	3,130	Hainan	375	60	56	162	97
Hunan	7,844	972	821	2,028	4,023	Ningxia	371	30	43	72	226
Henan	7,646	904	524	1,335	4,883	Qinghai	155	20	22	21	92
Heilongjiang	5,962	975	377	1,181	3,429	Xizang	9	2	0	7	0
Hebei	5,909	1,026	479	1,225	3,179						

A telecommunications, *B* consumer electronics, *C* computer, office machinery, *D* other ICT

Table 4 The number of patents by Chinese region in each domain for the three periods

Region	1985–1994				1995–2005				2006–2010			
	A	B	C	D	A	B	C	D	A	B	C	D
Anhui	38	30	83	273	268	90	253	817	643	324	701	2,337
Beijing	**554**	**346**	**1,010**	**2,161**	**6,698**	**1,646**	**6,303**	**5,569**	**16,092**	**6,147**	**17,013**	**13,351**
Fujian	73	41	88	218	504	239	532	896	1,586	1,014	1,919	2,016
Gansu	12	7	37	160	50	23	115	308	58	58	83	566
Guangdong	**216**	**172**	**315**	425	**13,744**	**2,972**	**8,190**	**4,157**	**39,632**	**14,934**	**22,787**	**12,306**
Guangxi	30	36	67	183	97	73	219	275	152	184	209	536
Guizhou	12	27	27	84	66	90	156	168	67	140	126	349
Hainan	0	2	9	11	22	16	102	28	38	38	51	58
Hebei	156	69	191	519	365	114	416	1,022	505	296	618	1,638
Henan	95	45	132	448	263	122	459	1,308	546	357	744	3,127
Heilongjiang	69	41	142	438	229	92	378	1,042	677	244	661	1,949
Hubei	97	76	159	582	776	245	668	1,884	1,648	802	1,626	3,732
Hunan	105	122	271	754	336	173	706	1,115	531	526	1,051	2,154
Jilin	64	35	105	499	234	100	348	1,146	288	273	320	1,528
Jiangsu	**321**	**195**	**393**	**1,106**	**1,495**	**685**	**1,933**	**3,659**	**5,127**	**3,213**	**6,610**	**13,908**
Jiangxi	35	23	97	209	114	69	354	323	199	177	401	704
Liaoning	**194**	100	**330**	**1,277**	461	538	947	2,398	915	1,155	1,342	3,729
Neimenggu	17	11	28	105	41	38	103	162	49	73	106	253
Ningxia	7	12	14	64	12	8	29	62	11	23	29	100
Qinghai	3	7	7	28	4	2	8	16	13	13	6	48
Shandong	137	105	289	**851**	813	**685**	1,162	2,742	1,904	**2,692**	3,648	7,381
Shanxi	39	31	90	246	63	70	172	377	196	182	251	892
Shaanxi	138	95	195	609	528	186	709	1,552	1,683	718	1,843	3,723
Shanghai	**216**	**144**	288	**926**	**3,318**	**1,813**	**3,138**	**4,811**	**7,312**	**4,508**	**9,470**	**11,539**

Table 4 continued

Region	1985–1994				1995–2005				2006–2010			
	A	B	C	D	A	B	C	D	A	B	C	D
Sichuan	164	91	197	553	663	459	771	1,298	2,442	1,663	2,365	3,091
Tianjin	96	76	141	463	445	249	583	1,565	841	1,311	1,356	3,305
Xizang	0	0	0	0	0	0	1	0	2	0	6	0
Xinjiang	21	22	31	88	47	36	93	211	32	93	118	304
Yunnan	29	38	65	194	65	34	189	392	81	113	232	620
Zhejiang	167	**128**	**290**	794	**1,218**	528	**1,404**	**3,205**	**4,758**	2,563	**4,620**	**9,783**
Chongqing	31	33	93	202	190	64	281	691	601	247	656	2,040

Table 5 Top 10 patent assignees and their types at each period

R	1985–1994			1995–2005			2006–2010		
	Assignee	No.	T	Assignee	No.	T	Assignee	No.	T
1	Tsinghua U	229	U	Huawei Co.	8,511	I	ZTE Co.	16,609	I
2	Zhejiang U	160	U	HFJP &HHP	2,452	I	Huawei Co.	14,726	I
3	Southeast U	113	U	ZTE Co.	2,400	I	HFJP & HHP	5,039	I
4	Xi'an JTU	98	U	LG (China) Co.	1,417	I	Zhejiang U	2,714	U
5	Tianjin U	73	U	Lenovo Co.	1,390	I	BUAA	1,999	U
6	SHIOFM,CAS	71	R	Tsinghua U	1,152	U	KONKA CO.	1,984	I
7	NJEC	53	U	SH LG BE Co.	1,110	I	Tsinghua U	1,968	U
8	HUST	51	U	Zhejiang U	879	U	H3C	1,798	I
9	BJIT	47	U	SHJTU	872	U	Tencent Co.	1,732	I
10	SN.54RIMEEM	45	R	SHIOFM, CAS	716	R	Southeast U	1,513	U

R Rank, *T* Type, *Tsinghua U* Tsinghua University, *Zhejiang U* Zhejiang University, *Southeast U* Southeast University, *Xi'an JTU* Xi'an Jiatong University, *Tianjin U* Tianjin University, *SHIOFM, CAS* Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, *NJEC* Nanjing Engineering College, *HUST* Huazhong University of Science and Technology, *BJIT* Beijing Institute of Technology, *SN.54RIMEEM* Shijiazhuang NO.54 Research Institute of the Mechanical and Electric Engineering Ministry, *Huawei Co.* Huawei Technologies Co. Ltd, *HFJP & HHP* Hong Fu Jin (Shen Zhen) Precision Ind. Co., Ltd & Hon Hai Precision Ind. Co., Ltd, *LG (China) Co.* LG electronics (China) research and development center Co., LTD, *SH LG BE Co.* Shanghai LG broadcasting electronics Co., LTD, *SHJTU* Shanghai Jiaotong University, *BUAA* Beijing University of Aeronautics and Astronautics, *SHIOFM,CAS* Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, *Tencent Co* Tencent (Shen Zhen) Technologies Co. Ltd

three, great changes took place in the leading performers. It is obvious that enterprises became the main force of innovation, and these prosperous domestic companies such as Huawei Corporation, ZTE Corporation and Lenovo Corporation play a leading role in patent production in the Chinese ICT sector. Several foreign subsidiaries were established in Mainland China, including Hong Fu Jin Precision (Taiwan), Hon Hai Precision (Taiwan), and LG Corporation (Korea), which has strengthened the innovation capabilities of Chinese enterprises. In addition, famous universities such as Tsinghua University, Zhejiang University and the Beijing University of Aeronautics and Astronautics (BUAA) remain major players in ICT patent production.

In the above, we focus on the changes in the leading performers in inventive activities at different periods. We now investigate the basic U-I-R collaboration patterns and their changes for different time periods and in different sub-domains based on the co-assignee relationship.

Figure 5 illustrates the assignee distribution of the non-collaboration patents. On the left side of the figure, the non-collaboration patents (i.e., with a single assignee) account for 90 % of the total number of patents, while only 10 % belong to collaboration patents (i.e., with more than one assignee). Among the non-collaboration patents, half of them are owned by industries (I) without any collaboration, 13 % by universities (U), and 7 % by research institutes (R) (right side of Fig. 6). The patents with a single U, I or R assignee make up 70 % of the non-collaboration patents, leaving 20 % occupied by other assignees, including individuals, the military and administrative organizations. These results confirm that industries are the main innovation actors, and that universities and research institutes are also important in the Chinese ICT patenting activities.

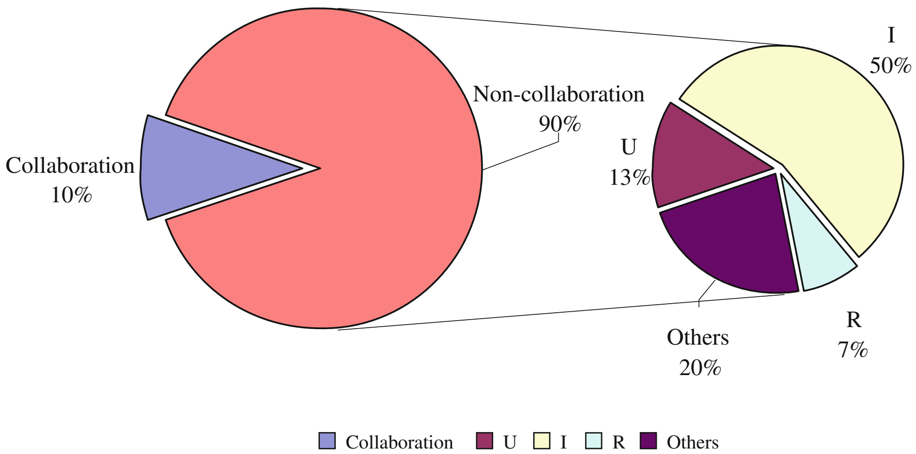


Fig. 5 The distribution of non-collaboration patents

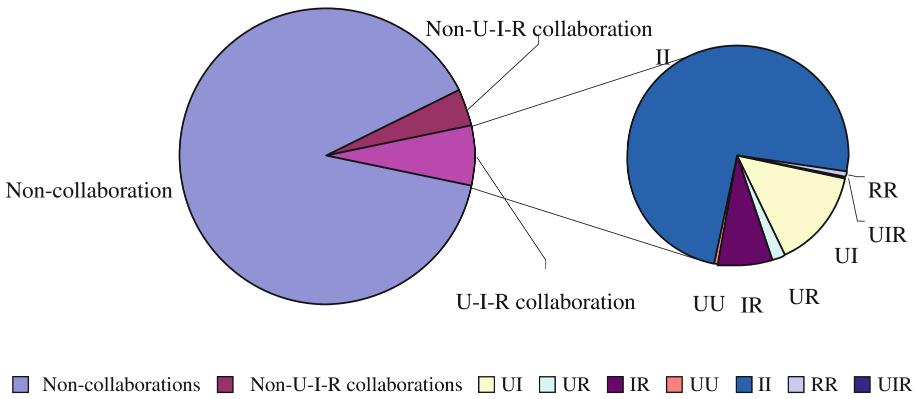


Fig. 6 The distribution of U-I-R collaboration patents

Next, we focus on those U-I-R collaboration patents. As shown in Figs. 5 and 6, the collaboration patents account for 10 % of the total patents; these include 6 % U-I-R collaboration patents and 4 % non-U-I-R collaboration patents. In terms of U-I-R collaboration patents, 74 % of the patents are co-assigned by industries, i.e., I-I collaboration patents, followed by U-I and I-R patents, which account for 14 and 7 %, respectively. The share of U-U, U-R, R-R and U-I-R collaboration patents is much lower.

Table 6 lists the outputs of U-I-R and their collaborations in each domain from 1985 to 2010. For the single assignees, regardless of the domain, the industries (I) have the largest patent production, followed by universities (U) and research institute (R). In terms of U-I-R co-assignees, I-I collaborations are the most popular pattern in the four domains, followed by U-I and I-R collaborations in the A, B and C domains. In the D domain, the number of U-I collaborations is almost equal to the number of I-R ones.

Table 7 provides the outputs of U-I-R and their collaborations for each period. For the single assignees, regardless of the period, the industries (I) own the largest number of

Table 6 The outputs of U-I-R and their collaborations in each domain

Domains	U	I	R	UI	UR	IR	UU	II	RR	UIR
A	13,171	82,603	7,733	1,142	165	192	51	3,860	70	3
B	3,133	25,350	1,589	413	20	88	32	2,759	4	4
C	13,652	54,247	4,942	1,074	66	344	40	9,814	31	1
D	28,010	60,049	17,166	1,585	344	1,588	82	5,213	130	66

Table 7 The outputs of U-I-R and their collaborations for each period

Period	U	I	R	UI	UR	IR	UU	II	RR	UIR
1985–1994	2,711	3,508	2,732	100	51	166	4	80	39	2
1995–2005	11,441	47,383	10,126	917	155	507	65	5,424	75	14
2006–2010	43,814	171,358	18,572	3,197	389	1,539	136	16,142	121	58

patents. In periods one and two, the universities own the same number of patents as the research institutes, but in period three, the patents granted to universities (U patents) significantly outnumber those of the research institutes. In terms of U-I-R co-assignees, I-R patents dominate in period one, followed by U-I and I-I patents, but their numbers are much lower. However, in periods two and three, I-I collaborations with explosive growth become the most popular pattern, followed by U-I and I-R collaborations.

We find an obvious increased level of U, I and R participation in Chinese ICT patent activities; in particular, organizations from industry have become the main force of innovation. The number of collaborations among universities (U), industry (I) and research institutes (R) has increased annually, but it is still weak. The linkages among universities (U), industry (I) and research institutes (R) should be strengthened in the future because collaboration is an important approach through which firms realize internal innovation and enhance innovative capabilities.

Conclusions

This paper examined the innovation performance of China in the ICT sector from 1985 to 2010; the period was split into three periods for comparison. Based on the SIPO database, all of the patents in the ICT sector with assignees from the Chinese regions have been included, and four domains are considered in this study. A bibliometric analysis was employed to conduct this rare comprehensive and long time-span study on the ICT sector in China.

Regarding the patent activity in the Chinese ICT sector, the number of patents granted by the SIPO continues on an upward trend. With a growth of over 30 % annually, there was an important increase in patent numbers between 2001 and 2010. In terms of each domain, the most notable increases are observed during period three (2006–2010). During this period, the number of patents granted by the SIPO in each domain is more than the total shares for the first two periods. This result is a sign of the growing importance of the ICT sector for economic growth and development. In addition, the proportion of invention-type patents in the total has increased over the past three periods. This result shows that the innovation capabilities of the Chinese ICT sector have improved with the reform of the science and technology systems.

At the regional level, the number of ICT patents is not evenly distributed, and a strong concentration has been shown. The three advanced municipalities and coastal provinces, i.e., Guangdong, Beijing, and Shanghai, have maintained their position as the top players, sharing over 50 % of the total Chinese patents in the ICT sector. In period one, the number of patents in all regions for each domain is much lower, but there is a bigger increase in the following two periods. In particular, the dramatic increase in patents during the shorter third period has been remarkable to witness. However, the total number of patents in less developed provinces, such as Neimenggu, Hainan, and Ningxia, is much lower and increased slowly over the past three periods due to a relatively inactive innovation effort from the Chinese ICT industry sector.

At the organizational level, in period one, most of top patent holders come from universities, which are the leading performers in the Chinese ICT sector. However, during periods two and three, great changes took place. Enterprises become the main force of innovation. Patents with a single U, I or R assignee comprise 70 % of the non-collaboration patents, and half of these are owned by a single assignee from industry (I). Prosperous domestic companies such as Huawei Corporation, ZTE Corporation and Lenovo Corporation play a leading role in the patent production of the Chinese ICT industry.

Collaboration patents account for 10 % of the total patents, of which 6 % are U-I-R collaboration patents. In terms of U-I-R co-assignees, I-I collaborations are the most popular pattern, followed by U-I and I-R collaborations. During the three periods, collaborations among universities (U), industry (I) and research institutes (R) have improved, but they are still rare. Collaboration should be reinforced in the future to help firms realize internal innovation and enhance innovative capabilities.

In conclusion, through the great importance that the government and domestic enterprises place on technology R&D and patent protection, significant improvements in the Chinese ICT sector have been witnessed, but the patent performance of Chinese regions and organizations still needs to be improved. Regional policies are important instruments to support the competitiveness of ICT innovation systems because they foster collaboration networks among the different actors involved in R&D&I activities, particularly for SMEs (Rojo and Gómez 2006). Enterprises have gradually become the primary body of technological innovation in recent years, and such leading enterprises as Huawei Corporation, ZTE Corporation have emerged in the Chinese ICT sector. However, a further analysis of all ICT patents granted by the SIPO, including foreign patent assignees, finds that 17 of the top 20 enterprises by patent numbers are foreign companies (Zhang et al. 2011). This result indicates that the innovation capabilities of most Chinese ICT enterprises should be further enhanced by increasing R&D inputs, building up research centers, conducting major scientific and technological projects, deepening the collaboration among industry-university-research institutes, and promoting the flow of capital, techniques and talent to enterprises.

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