

# International scientific and technological collaboration of China from 2004 to 2008: a perspective from paper and patent analysis

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**Abstract** Since China adopted Open-Up and Reformed Policy for global collaboration, China's science and technology have experienced an astounding growth. Papers and patents encompass valuable scientific and technological (S&T) information and collaborative efforts. This article studies China's international S&T collaboration from the perspective of paper and patent analysis. The results show that China's total papers and patents have continuously increased from 2004 to 2008, the papers and patents resulting from China's international collaboration also present a steady growth. However, there is a decline in the share of international collaboration papers and patents with a certain range due to the rapid independent R&D. China's international scientific collaboration (ISC) is broadly distributed over many countries, the USA being the most important ISC partners. China's international technological collaboration (ITC) is mainly carried out with USA and Taiwan, and Taiwan has been the most significant ITC partner of when taking countries' patent output into account. Besides, ISC shows a continuous raise of Chinese papers' citation. Even the countries with a small amount of papers and ISC with China, exert a positive influence on the impact of citation of Chinese papers as well. However, ITC does not always play an active role in the improvement of citation impact of Chinese patents.

**Keywords** International scientific and technological collaboration · Paper · Patent

**Mathematics Subject Classifications (2000).** 62-07

**JEL Classifications** O30

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## Introduction

In recent years, economic globalization has increasingly widened. The global flow of scientific and technological (S&T) resources has developed faster, and the major global issues have been more prominent. Owing to the trend, this study shows that strengthening the international S&T collaboration can make an influential use for international S&T resources to promote its economic development, and it can be a general consensus between governments and business community. By collaboration, countries (regions) can share and pass knowledge, set up networks of academic communication and generate new academic thoughts. Meanwhile, research cost is decreased and research productivity is increased (Beaver 2001; Katz and Martin 1997). International S&T collaborations usually result in greater visibility and higher citation impact. Additionally, larger multinational projects often produce a higher citation rate (Glanzel and De Lange 2002). Therefore, the advancement in S&T is no longer confined to the S&T advancement of individual nations. No matter the view point is from the depth and width of S&T research projects, or from the organization and scale of S&T activities, S&T is entering a new era to promote a better economic development through international collaboration.

Since the adoption of the Opening-up and Reform Policy in 1978, China has achieved a spectacular growth in both of economy and S&T development. However, as a developing country, certain gaps have existed between China and the developed countries. It is even more necessary for China to develop various forms of international collaboration, making a full use of information, technology, capital and equipment abroad to upgrade its own research and development (R&D) capability to narrow the gaps. China frequently resorted to international S&T collaboration, especially in recent years. Under the guidance and support of government, China's foreign cooperation and exchanges in S&T have obtained rapid and flourishing development. In 2001, the Ministry of Science and Technology of China (MOST) set up a "key of international S&T cooperation project", and the special funds were earmarked for promoting China's international S&T collaboration and the exchanging development. In 2009, the amount of special funds has exceeded 500 million RMB, which is 10 times higher than the amount in 2001. Till the end of 2009, China has established S&T collaboration relations with 152 countries or regions, and has signed 104 inter-governmental S&T collaboration agreements with 97 countries. As shown by the above statements, international S&T collaboration has shown a good momentum in the development.

The importance of the co-author papers and patents has grown recently (Chang 2010). Because of the ever-growing importance of S&T collaboration of China, more and more institutes and scholars have paid more attention to international S&T collaboration studies of China and applied the corresponding results to policy references. Guo et al. (2000) took Science Citation Index (SCI) to study China's 1991–1998 international collaboration. It shows the Chinese publications of international collaboration have annually increased. Physics occupies 30.2% of the total internationally collaborated publications, which is the most active international collaboration area. Liu and Chang (2001) analyzed international collaboration in distribution of subjects, based on the SCI data related to China and other 33 countries and regions from 1994 to 1998. He (2009) also investigated the international collaboration pattern of China and the nations of G7, based on bibliometric method. It also showed how China formulated corresponding policies of international collaboration to improve its scientific outputs and impacts. Zhou and Glanzel (2010) further studied the growth of competitiveness is accompanied by the intensification of collaboration in China, based on the publications in Science Citation Index Expanded (SCIE). The dynamics and national characteristics of China's co-operation in global context are analyzed as well.

Research profile and citation impact of international collaboration are also investigated with respect to the corresponding domestic ‘standards’. Ma et al. (2009) founded the pattern of technological collaboration in the global context between China and the selected countries by retrieving patent data from United States Patents and Trademark Office (USPTO). It shows the increasing collaborations in inventive activities between China and other major innovative countries over the past decade. Guan and He (2007) investigated the science-technology connection in the context of Chinese regions as well as industrial sectors by using the scientific non-patent references (NPRs) within patents, based on the database of USPTO. It suggests that the patents and their corresponding scientific citations are related in different ways. The distribution of scientific references covered by SCI was also studied in detail.

According to the above, most of the studies of China’s international S&T collaboration are focused on papers (which is pertaining to international scientific collaborations (ISC)), or on patents (which is related to international technological collaboration (ITC)). However, both of ISC and ITC are equally important components of international S&T collaboration, and necessary in encouraging economic development and enhancing national competitiveness. According to the diversity between scientific research and technological innovation, the ISC and ITC of one country must show the distinct characteristics and different cooperation modes. Therefore, in the present research, the international S&T collaboration of China has been investigated with a combination of ISC and ITC studies. Neither the analysis of ISC nor the analysis of ITC can reflect an entire picture and development trends of international S&T collaboration.

In order to examine the international S&T collaboration development of China in recent years, the present study firstly reviews the history of selected papers and patents, then investigates the growth of competitiveness in science and technology which is accompanied by intensification of international collaborations in China. Secondly, it moves on the discussion about China’s major partners in scientific research and technological innovation. Additionally, comparison between citation impact of international S&T collaboration and China’s total “standards” will also be elaborated in the end of the study.

## Methodology

### The data

*Paper:* China’s international collaboration papers are mainly published in international journals. According to the data from Chinese Scientific and Technological Papers, and Citations Database (CSTPC), among the 1600 series of published Chinese domestic science technology, only 1.5% of the publications were international collaboration in 2004. At the same time, 20.8% of the total Chinese publications in SCI were international collaboration publications (He 2009). Consequently, the paper data of this study has been retrieved from the Web of Science (WOS) and downloaded online in January, 2009, including all the papers with index year from 2004 to 2008.

The papers were assigned to the related countries based on corporate addresses given in the by-line of publications. All the countries involved in the address field are taken into consideration. In the present study, China’s international collaboration papers were those papers with at least one Chinese corporate address and one foreign corporate address in the by-line of publication.

When it comes to the studies of China's major ISC partners, if there are more than one foreign country in the by-line, such as U.S. and Japan, this paper would not only be counted as Sino-US collaboration, but also be regarded as Sino-Japan collaboration.

*Patent:* It is true that China's domestic patent applications are important indicators of China's technological capability. However, international patent activities and patent applications to USPTO are more essential, because it is more difficult for China's patent applications to get approved by USPTO. The USPTO-granted patent has a higher technological value, and it can indicate a higher quality of the invention. Thus, the patent data for this study has been retrieved from the USPTO database and downloaded online on April 19th, 2009, which include all the USPTO issued patents from 2004 to 2008.

Patents of a country can be identified by two ways in the USPTO database: the patents of assignee country and the patents of inventor country (Bhattacharya 2004). Usually, people take inventor country patents (i.e., the inventor country is the target that the patent will be attributed to), because it can reveal the inventive/innovative activity in a country. Therefore, in the present study, China's international collaboration patents are those with at least one Chinese inventor address and one foreign inventor address.

When it comes to the studies of China's major ITC partners, if there are more than one foreign country among inventor addresses, such as U.S. and Japan, this patent would not only be counted as Sino-US collaboration, but also be regarded as Sino-Japan collaboration.

#### Paper/Patent Indicators

*Salton's Measure (S):* Salton's measure is used to define indicator of strength of mutual collaboration link between two countries, which is the number of joint papers/patents divided by the square root of the product of the number (i.e., the geometric mean) of total papers/patents of two countries. This indicator is a method for measuring relative strength between the two countries of collaboration, which takes the paper/patent size of two collaborated countries into account (Glanzel 2001; Zhou and Glanzel 2010).

$$S_{ij} = P_{ij} / \sqrt{P_i \times P_j}$$

$P_{ij}$  is the number of joint papers/patents between country  $i$  and country  $j$ ,  $P_i$  is the number of total papers/patents of country  $i$ ,  $P_j$  is the number of total papers/patents of country  $j$ .

*CPP/FCSm:* The average number of citations of papers/patents that a country has received, divided by the average number of citations that the whole world received. If the ratio CPP/FCSm is above 1.0, it means the country's paper/patent is frequently cited and has brought more influence than the world average (Moed et al. 1995; Van Raan 1996). Recently, this indicator (the so-called crown indicator) has shown a logical flaw and there is a difference between ratios of averages (ROA) and averages of ratios (AOR). However, for large numbers of papers, the difference is not big. Since the large numbers of papers and citations are involved, variations tend to be averaged out (Lariviere and Gingras 2011). Thus, CPP/FCSm is used in this paper to evaluate the citation impact of papers and patents.

$$\text{CPP/FCSm} = \frac{C_i/N_i}{C_w/N_w}$$

$C_i$  is the number of total citations received by country  $i$ 's papers/patents,  $N_i$  is the number of total papers/patents of country  $i$ ,  $C_w$  is the number of total citations received by the papers/patents of whole world,  $N_w$  is the number of total papers/patents of the whole world.

## Results and discussion

### China's international S&T collaboration

Since the adoption of the Open-up and Reformed Policy, China has achieved a spectacular growth in both of economy and S&T competitiveness. As an important output of science research and technology innovation, the number of China's papers and patents have showed an obvious increase in recent years, according to Table 1. The total number of papers and patents in China over the past 5 years are 405,420 and 8,016, respectively. According to the above, the number of papers in China increased from 52,441 in 2004 to 111,131 in 2008, with its share in the world continually growing from 5.75 to 9.23%. Patents also exhibited a sustained growth, with its share in the world increasing from 0.52 to 1.43% in 2008. This might be resulted from China's heavy emphasis on R&D expenditure and desire to rely on S&T innovation to create more values. According to OECD statistics, since 2005, R&D investment in China has increased more than 20%, and China has become the second largest country in R&D investment among the world.

Due to the increase of total papers and patents, international collaboration papers and patents in China also exhibited an obvious increase during the past 5 years, as illustrated in Table 2. However, the share of international collaboration papers in China's total papers declined slowly all along this period, decreasing from 25.9% in 2004 to 24.2% in 2008. The share of China's international collaboration patents once showed a growing indication in 2006. Afterward, there was a sharp decline by over 4%.

Figure 1 illustrates the shares in graphic. There is a slow decline in the share of international collaboration papers of China's total papers. The decline of China's collaboration papers has also been observed by Glanzel, Debackere and Meyer. In their study, the share of international collaboration papers decreased from 26.2% in 1998 to 21.9% in 2005 (Glanzel et al. 2008). Rousseau (2008) introduced the barycentre method, which could yield visual representation to well illustrate this findings. The share of international

**Table 1** The number of CHINA'S total papers and patents by year

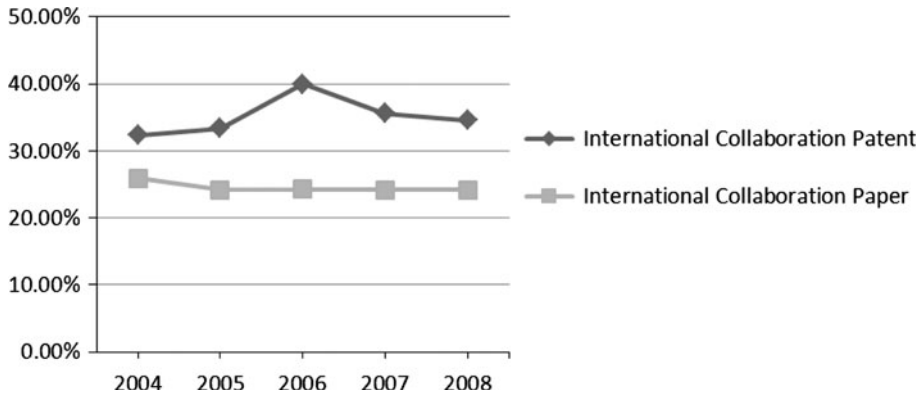
Year	Total papers (share)	Total patents (share)
2004	52,441 (5.75%)	951 (0.52%)
2005	72,238 (6.59%)	963 (0.61%)
2006	80,302 (7.77%)	1,621 (0.83%)
2007	89,308 (8.40%)	1,828 (1.00%)
2008	111,131 (9.23%)	2,653 (1.43%)
2004–2008	405,420	8,016

Data compiled by authors for this study

**Table 2** The number of China's international collaboration papers and patents by year

Year	International collaboration papers (share)	International collaboration patents (share)
2004	13,595 (25.9%)	307 (32.3%)
2005	17,536 (24.3%)	322 (33.4%)
2006	19,534 (24.3%)	649 (40.0%)
2007	21,605 (24.2%)	651 (35.6%)
2008	26,918 (24.2%)	917 (34.6%)
2004–2008	99,188	2,846

Data compiled by authors for this study



**Fig. 1** The shares of China's international collaboration papers and patents by year

**Table 3** The number of China's international collaboration patents issued to foreign assignees by year

Foreign companies	Countries (regions)	2004	2005	2006	2007	2008	Total
Hon hai precision Ind. Co., Ltd.	Taiwan	107	90	246	230	389	1062
Microsoft corporation	USA	14	17	43	44	77	195
Inventec appliances corp.	Taiwan	11	13	22	16	15	77
Intel corporation	USA	2	1	10	15	25	53
Metrologic instruments Inc.	USA	0	1	8	22	12	43
General electric company	USA	2	4	4	12	16	38
Headway technologies, Inc.	USA	4	11	6	6	3	30
Procter and gamble company	USA	6	4	8	4	7	29
Nokia corporation	Finland	5	3	4	3	13	28
Brinkmann corporation	Germany	1	0	0	6	20	27
IBM corporation	USA	4	1	2	5	10	22
GEM services, Inc.	USA	11	2	3	1	3	20

Data compiled by authors for this study

collaboration patents also distinctly decreased after 2006. This is a clear indicator tells that China's S&T capability has remained strengthening in recent years. China's independent R&D ability rapidly developed, and international S&T collaboration gradually lagged domestic S&T innovation development of China in behind.

Figure 1 also illustrates that the share of China's international collaboration patents has remained above 30% over the past decade. In most of the countries, the share of international collaboration patents was about 15%. This share in China was much higher; probably because loads of foreign companies have set up research institutes in China. Chinese and foreign staff carried out more joint research and co-invented patents. Detailed assignee studies reveal that lots of China's international collaboration patents were issued to foreign companies, and the research organizations are located in China. According to Table 3, U.S. and Taiwan companies occupy a large proportion.

## Major international S&amp;T collaboration partners

*(Unidirectional) affinity*

Countries (regions) with relatively higher share in China's papers from 2004 to 2008 are shown in Table 4. Among the ISC partners of China, USA took the biggest share in China's international collaboration papers, about 8–9% of China's papers are jointly published with authors from USA. Furthermore, collaborative relation between China and USA has strengthened year by year, with its share increasing from 8.3% in 2004 to 9.0% in 2008. Japan has always ranked in the second place, but its share in China's papers continued declining in the past 5 years, as shown in Fig. 2.

Besides USA and Japan, the top 10 ISC partners of China are Germany, England, Canada, Australia, France, South Korea, Singapore and Taiwan. Even though there's a certain margin of the change among ten countries (regions), those countries have still been the most important contributors to Chinese international collaboration papers, as shown in Figs. 2 and 3. Furthermore, there was a slight difference in the share of the other nine countries (regions), except USA. It reflects that China's international cooperation in scientific research is broadly distributed, not only influences in single or two countries (regions).

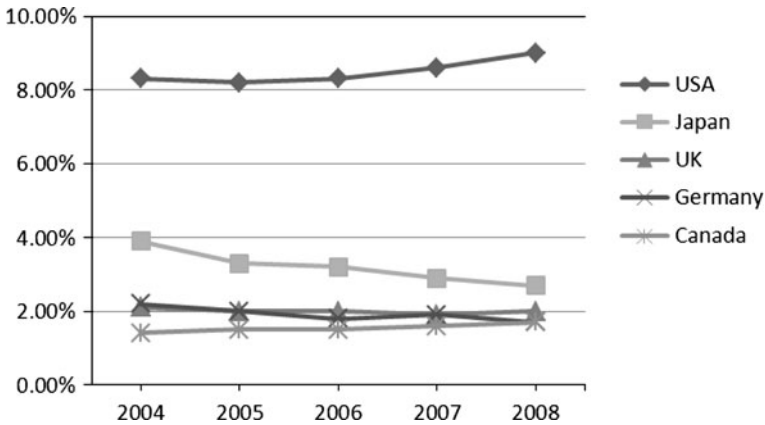
Countries (regions) with relatively higher share in China's patents from 2004 to 2008 are shown in Table 5. Among the ITC partners of China, USA and Taiwan played a leading role, about 30% of China's patents were applied by inventors from USA and Taiwan. Although the shares of USA and Taiwan exhibited a certain degree of change during the past 5 years, they rank as Top 2 with noticeable rates, as shown in Fig. 4. The situation is unlike the broadly international collaboration in scientific research, China's international collaboration in technology innovation was mainly carried out with inventors from US and Taiwan, as is demonstrated in Table 3. Many of US and Taiwan companies have established research institutes in China, Chinese and foreign staff carried out the joint research and invented patents together in foreign enterprises.

The other major ITC partners are Japan, Germany, Singapore, Canada, England, Korea, France, Finland, Switzerland, Australia and Belgium separately. The shares of these countries have kept changing during this period. According to Fig. 5, the importance of

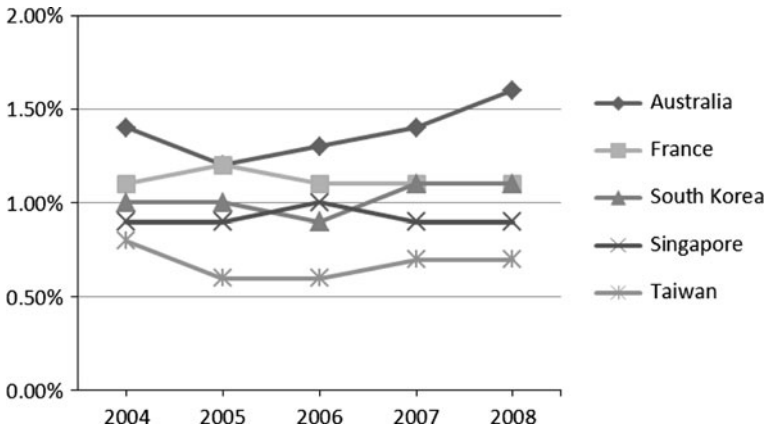
**Table 4** Top 10 countries (regions) with high share in China's papers

Country (regions)	2004 Rank (share)	2005 Rank (share)	2006 Rank (share)	2007 Rank (share)	2008 Rank (share)	2004–2008 Rank (share)
USA	1 (8.3%)	1 (8.2%)	1 (8.3%)	1 (8.6%)	1 (9.0%)	1 (8.5%)
Japan	2 (3.9%)	2 (3.3%)	2 (3.2%)	2 (2.9%)	2 (2.7%)	2 (3.1%)
England	4 (2.1%)	3 (2.0%)	3 (2.0%)	3 (1.9%)	3 (2.0%)	3 (2.0%)
Germany	3 (2.2%)	3 (2.0%)	4 (1.8%)	3 (1.9%)	4 (1.7%)	4 (1.9%)
Canada	5 (1.4%)	5 (1.5%)	5 (1.5%)	5 (1.6%)	4 (1.7%)	5 (1.6%)
Australia	5 (1.4%)	6 (1.2%)	6 (1.3%)	6 (1.4%)	6 (1.6%)	6 (1.4%)
France	7 (1.1%)	6 (1.2%)	7 (1.1%)	7 (1.1%)	7 (1.1%)	7 (1.1%)
South Korea	8 (1.0%)	8 (1.0%)	9 (0.9%)	7 (1.1%)	7 (1.1%)	8 (1.0%)
Singapore	9 (0.9%)	9 (0.9%)	8 (1.0%)	9 (0.9%)	9 (0.9%)	9 (0.9%)
Taiwan	10 (0.8%)	10 (0.6%)	10 (0.6%)	10 (0.7%)	10 (0.7%)	10 (0.7%)

Data compiled by authors for this study



**Fig. 2** The shares of important contributors (ranked 1st–5th) to China's international collaboration papers by year



**Fig. 3** The shares of important contributors (Ranked 6–10th) to China's international collaboration papers by year

Japan and Germany to China has strengthened year by year; while, Singapore has rapidly dropped, with its share decreasing from 2.2% in 2004 to 0.6% in 2008.

### *Mutual collaboration strength*

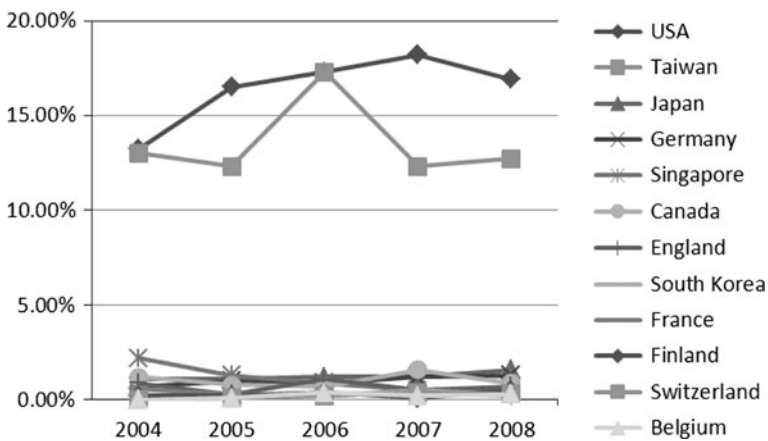
A country with larger amounts of papers/patents may get more cooperative chance to publish papers/apply patents with other countries. Therefore, the country may take a greater part of share in selected country's international collaboration papers/patents. For example, due to their largest quantity of paper publications in the world, USA can still easily hold a leading position when they are in international collaboration papers with other countries, though the number of the joint papers with other countries only takes a very small share of that of USA. In other words, USA is important to the selected country, but it's not true vice versa. As a result, to eliminate the effects from the size of countries,



**Table 5** Top 10 countries (regions) with high share in China's patents

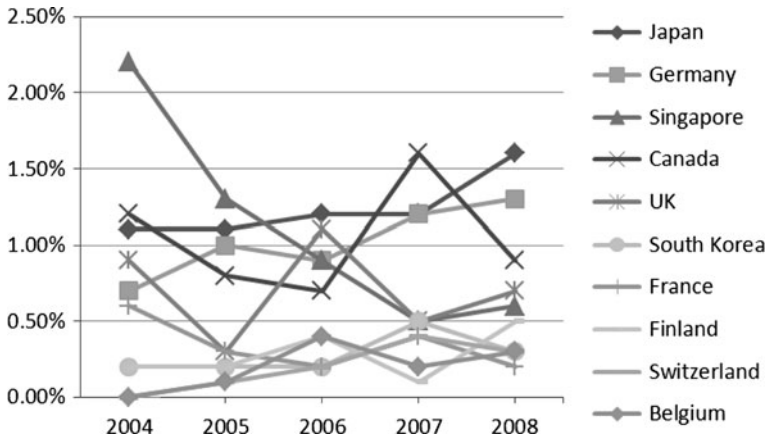
Country (regions)	2004 Rank (share)	2005 Rank (share)	2006 Rank (share)	2007 Rank (share)	2008 Rank (share)	2004-2008 Rank (share)
USA	1 (13.2%)	1 (16.5%)	1 (17.3%)	1 (18.2%)	1 (16.9%)	1 (16.8%)
Taiwan	2 (13.0%)	2 (12.2%)	1 (17.3%)	2 (12.3%)	2 (12.7%)	2 (13.5%)
Japan	5 (1.1%)	4 (1.3%)	3 (1.2%)	3 (1.2%)	3 (1.6%)	3 (1.3%)
Germany	7 (0.7%)	5 (1.0%)	6 (0.9%)	3 (1.2%)	4 (1.3%)	4 (1.1%)
Singapore	3 (2.2%)	3 (1.5%)	5 (1.0%)	6 (0.5%)	6 (0.6%)	5 (1.0%)
Canada	4 (1.2%)	6 (0.8%)	7 (0.7%)	5 (0.6%)	5 (0.9%)	6 (0.8%)
England	6 (0.9%)	7 (0.3%)	4 (1.1%)	6 (0.5%)	7 (0.5%)	7 (0.7%)
South Korea	–	9 (0.2%)	10 (0.2%)	6 (0.5%)	9 (0.3%)	8 (0.3%)
France	8 (0.6%)	7 (0.3%)	–	9 (0.4%)	–	8 (0.3%)
Finland	9 (0.2%)	9 (0.2%)	8 (0.4%)	–	7 (0.5%)	8 (0.3%)
Australia	9 (0.2%)	–	–	–	–	–
Belgium	–	–	8 (0.4%)	–	–	–
Switzerland	–	–	–	9 (0.4%)	9 (0.3%)	–

Data compiled by authors for this study

**Fig. 4** The shares of important contributors to China's international collaboration patents by year

Salton's measure works are for reflecting the mutual strength between the collaboration of two countries.

Table 6 shows the values of Salton's measure (S) of ISC between China and other countries (regions). Comparing to the data from Tables 4 and 6, the top 10 countries (regions) that accounted for large proportion in China's total papers, also exhibited the strong mutual collaboration with China. As USA stands as a leading position in the Salton's measure rankings, it can also be regarded as China's most important scientific research partners in terms of the strength of mutual collaboration and the affinity of unidirectional collaboration. The collaboration between Taiwan and Malaysia became weaker since Malaysia did not appear in the ranking after 2005, as shown in Table 6. Collaboration



**Fig. 5** The shares of important contributors (except USA and Taiwan) to China's international collaboration patents by year

**Table 6** Top 10 countries (regions) with strong mutual collaboration in China's ISC

Country (regions)	2004 Rank (S)	2005 Rank (S)	2006 Rank (S)	2007 Rank (S)	2008 Rank (S)	2004–2008 Rank (S)
USA	1 (0.032)	1 (0.034)	1 (0.038)	1 (0.042)	1 (0.047)	1 (0.039)
Singapore	3 (0.026)	2 (0.029)	2 (0.032)	2 (0.031)	2 (0.032)	2 (0.030)
Japan	2 (0.031)	2 (0.029)	3 (0.030)	3 (0.030)	3 (0.030)	2 (0.030)
Australia	4 (0.018)	4 (0.017)	4 (0.019)	4 (0.022)	4 (0.024)	4 (0.020)
Canada	10 (0.014)	6 (0.016)	5 (0.018)	5 (0.019)	5 (0.019)	5 (0.018)
Germany	4 (0.018)	6 (0.016)	6 (0.017)	6 (0.018)	6 (0.018)	6 (0.017)
England	7 (0.015)	6 (0.016)	6 (0.017)	8 (0.017)	8 (0.017)	6 (0.017)
South Korea	7 (0.015)	9 (0.015)	8 (0.015)	6 (0.018)	6 (0.018)	8 (0.016)
Taiwan	7 (0.015)	–	9 (0.012)	9 (0.014)	9 (0.014)	9 (0.014)
France	–	10 (0.012)	9 (0.012)	10 (0.013)	10 (0.013)	10 (0.012)
Malaysia	6 (0.016)	4 (0.017)	–	–	–	–

Data compiled by authors for this study

relation between China and Singapore is unusually striking when Singapore's general productivity is added into account. According to Table 6, Singapore has ranked as the 2nd place since 2005.

Table 7 shows the values of Salton's measure (S) of ITC between China and other countries (regions). When countries' patent output was taken into account, Taiwan holds the strongest mutual collaboration with China, followed by USA and Singapore. As the countries with a result of high patent, for instance, Korea holds a large share of China's international collaboration patents though; it is still not China's most important partners in terms of mutual collaboration. It is worth to mention that some countries with small patent output have greater mutual collaboration strength with China during the past decade, such as Philippines, Malaysia, Thailand, Turkey, Cyprus, Jamaica and United Emirates.

**Table 7** Top 10 countries (regions) with strong mutual collaboration in China's ITC

Country (regions)	2004 Rank (S)	2005 Rank (S)	2006 Rank (S)	2007 Rank (S)	2008 Rank (S)	2004–2008 Rank (S)
Taiwan	1 (0.047)	1 (0.048)	1 (0.077)	1 (0.060)	1 (0.072)	1 (0.062)
USA	3 (0.013)	3 (0.018)	3 (0.022)	2 (0.025)	2 (0.028)	2 (0.021)
Singapore	2 (0.028)	2 (0.019)	4 (0.015)	3 (0.009)	3 (0.012)	3 (0.016)
Canada	4 (0.005)	5 (0.004)	9 (0.004)	7 (0.004)	4 (0.007)	4 (0.005)
Germany	9 (0.002)	6 (0.003)	–	6 (0.005)	6 (0.006)	5 (0.004)
England	6 (0.004)	–	6 (0.006)	10 (0.003)	9 (0.004)	5 (0.004)
Finland	9 (0.002)	7 (0.002)	8 (0.005)	–	4 (0.007)	5 (0.004)
Jamaica	–	–	2 (0.025)	–	–	8 (0.003)
Belgium	–	–	6 (0.006)	–	7 (0.005)	8 (0.003)
Japan	–	7 (0.002)	–	–	9 (0.004)	8 (0.003)
Philippines	4 (0.005)	–	–	7 (0.004)	–	–
France	7 (0.003)	–	–	–	–	–
Malaysia	7 (0.003)	–	–	–	–	–
Thailand	–	4 (0.005)	–	–	–	–
Netherlands	–	7 (0.002)	–	–	–	–
Spain	–	7 (0.002)	–	–	–	–
Cyprus	–	–	5 (0.009)	–	–	–
Turkey	–	–	9 (0.004)	4 (0.008)	–	–
United Emirates	–	–	–	5 (0.006)	7 (0.005)	–
Switzerland	–	–	–	7 (0.004)	–	–

Data compiled by authors for this study

**Table 8** The citation impact of China's papers compared to the world average (CPP/FCSm) by year

Data compiled by authors for this study

Year	International collaboration	Total
2004	1.16	0.76
2005	1.23	0.80
2006	1.19	0.80
2007	1.22	0.82
2008	1.19	0.76

### Citation impact of international S&T collaboration

The citation impact of China's total and international collaboration papers compared to the world average, CPP/FCSm, has been investigated in Table 8. Neither China's total papers nor China's international collaboration papers have shown any significant change over the past 5 years. The CPP/FCSm of China's international collaboration papers was higher than that of China's total papers every year. In other words, international collaboration increases Chinese papers' citation impact all along the period. Furthermore, China's international collaboration papers have always been above the world average, with the value of CPP/FCSm higher than 1.0 all through the past 5 years.

**Table 9** Top 10 countries (regions) with high citation impact in China's international collaboration papers

Rank	2004 Country/region (CPP/FCSm)	2005 Country/region (CPP/FCSm)	2006 Country/region (CPP/FCSm)	2007 Country/region (CPP/FCSm)	2008 Country/region (CPP/FCSm)
1	Indonesia (8.28)	Croatia (8.14)	Mexico (8.93)	Brazil (5.00)	Bulgaria (11.21)
2	Croatia (6.23)	South Africa (5.30)	Israel (8.46)	Argentina (4.33)	Finland (5.34)
3	Argentina (5.70)	Czech (5.26)	Ireland (7.98)	Hungary (4.18)	Vietnam (5.23)
4	Ecuador (5.03)	Brazil (4.86)	Finland (6.83)	Ecuador (4.09)	Indonesia (5.15)
5	Vietnam (4.81)	Greece (4.74)	Switzerland (5.35)	Croatia (4.05)	Brazil (4.92)
6	Colombia (4.57)	Poland (4.70)	Spain (5.34)	Czech (3.71)	Romania (4.88)
7	Thailand (4.55)	Israel (4.64)	India (4.91)	Slovenia (3.30)	Ecuador (4.76)
8	Czech (4.54)	Philippines (4.27)	Hungary (4.50)	Colombia (3.09)	Argentina (4.65)
9	Slovenia (4.35)	Thailand (3.94)	Argentina (4.31)	Turkey (3.06)	Hungary (4.43)
10	Poland (4.11)	Norway (3.90)	Brazil (4.25)	Mexico (3.03)	Egypt (4.43)

Data compiled by authors for this study

Detailed studies of the countries/regions that exhibit the impact of high citation in the international collaboration papers of China are conducted. As is shown in Table 9, the top 10 countries (regions) with high citation impact in China's international collaboration papers, as well as their rankings, have changed every year. It is worth to mention that there are many developing countries with relative low paper output appear in the rankings, such as Indonesia, Vietnam, Philippines, Thailand, and so on. Although the amount of international collaboration papers between these countries and China are quite small, around 5–50 every year. Sometimes those countries have even received higher citation impacts. For example, there are only 6 international collaboration papers between Indonesia and China in 2004, but these 6 papers have received 429 citations. Among the papers, one related to oncology and radiology, 'Multinational assessment of some operational costs of teletherapy', has been cited 338 times. There are only 7 international collaboration papers between Ecuador and China in 2004, all of them focus on physics discipline. And these 7 papers have received more than 300 citations.

For the countries/regions with larger amounts of international scientific collaboration with China, the citation impacts (CPP/FCSm) have been studied as well. As Table 10 shows that the CPP/FCSm of these countries/regions in every year is higher than the CPP/FCSm of total paper in China of Table 8. It reflects that the countries (regions) with more international scientific collaboration (ISC) with China also play an active role in enhancing the citation impact and quality of paper in China.

Table 11 provides the citation impact of the total in and China's international collaboration patents compared to the worldwide average. Both of the citation impact of the total in China and international collaboration patents of China are below the average (the values are lower than 1.0) during the past 5 years. The citation impact of the total patent in China have kept declining in every year, with the CPP/FCSm decreasing from 0.66 in 2004 to 0.17 in 2008. The international cooperation in technology innovation once played an active role in raising citation impact of China patent before the year of 2007. However, from 2007 to 2008, the CPP/FCSm of international collaboration patents of China was lower than that of the total patent in China. It reflects that the international collaboration does not always pay off in the technology innovation of China; it's unlike the continual raising effect of international collaboration to the citation impact of Chinese papers.

**Table 10** The citation impact of top 10 countries (regions) with high share and with strong mutual collaboration with China in China's international collaboration papers

Country (regions)	2004 CPP/FCSm	2005 CPP/FCSm	2006 CPP/FCSm	2007 CPP/FCSm	2008 CPP/FCSm
USA	1.61	1.71	1.66	1.61	1.61
Japan	1.14	1.23	1.40	1.25	1.34
England	1.61	1.87	1.94	1.61	1.82
Germany	1.63	2.01	2.28	1.83	2.03
Canada	1.23	1.74	1.77	1.57	1.63
Australia	1.63	1.68	1.82	1.33	1.68
France	2.13	2.41	2.59	1.90	2.28
South Korea	1.47	1.54	2.04	1.44	1.65
Singapore	1.55	1.26	1.08	1.24	1.33
Taiwan	1.86	1.80	1.33	1.35	1.41

Data compiled by authors for this study

**Table 11** The citation impact of China's patents compared to the world average (CPP/FCSm) by year

Year	International Collaboration	Total
2004	0.67	0.66
2005	0.84	0.61
2006	0.56	0.54
2007	0.34	0.39
2008	0.17	0.17

Data compiled by authors for this study

**Table 12** The countries (regions) with higher citation impact than China's total patents year by year

Rank	2004 Country/region (CPP/FCSm)	2005 Country/region (CPP/FCSm)	2006 Country/region (CPP/FCSm)	2007 Country/region (CPP/FCSm)	2008 Country/region (CPP/FCSm)
1	South Korea (3.30)	Netherlands (2.18)	Cyprus (1.05)	Russia (1.03)	Denmark (1.31)
2	Japan (1.49)	Thailand (2.05)	Taiwan (0.71)	England (0.93)	Finland (0.36)
3	Canada (1.44)	France (1.20)	Czech (0.70)	Japan (0.61)	Taiwan (0.21)
4	England (1.28)	Austria (1.03)	Belgium (0.55)	Taiwan (0.56)	USA (0.20)
5	Netherlands (1.13)	USA (0.92)			
6	Malaysia (1.13)	Taiwan (0.90)			
7		England (0.86)			

Data compiled by authors for this study

The countries/regions exhibit higher figures of CPP/FCSm than the figures of yearly total patents of China are studied. As is shown in Table 12, these countries (regions) have kept changing year by year. There's no country/region play an active role in enhancing the citation impact of patents of China all along the period.

## Conclusion

The collaborative information in paper and patent documents are regarded as an effective tool to study international S&T collaboration development of a country. Through the analysis of China's international collaboration papers and patents during 2004–2008, the research herein draws the following conclusion.

China's ISC&ITC shows a flourishing growth; while compared to the rapid development of independent R&D, China's international S&T collaboration has gradually fallen behind.

According to the increase in total papers and patents, the international collaboration papers and patents in China also exhibit an obvious growth during the past 5 years. This reveals that China's international S&T collaboration has developed rapidly and flourishingly due to the guidance and support of its government.

However, the share of international collaboration papers in China's total papers shows a slow decline, and the share of international collaboration patents decreased distinctly after the year of 2006. It clearly indicates that China has obtained to a level of sufficient independent R&D capability, and China's international S&T collaboration development has gradually lagged behind the pace of its domestic S&T development.

The share of China's international collaboration patents was a bit higher if it's compared to the other countries. Many foreign companies have set up research institutes in China might be an influential factor; Chinese and foreign staff have carried out more joint research and co-invented patents.

China's ISC is broadly distributed across the countries (regions), and USA is China's most important ISC partners. While China's ITC is mainly carried out with USA and Taiwan, Taiwan has become China's most important ITC partner when countries' patent output is taken into account.

China's international cooperation in scientific research is broadly distributed, and it's not only concentrated on one or two countries (regions). The important ISC partners of China respectively are USA, Japan, Germany, UK, Canada, Australia, France, Korea, Singapore and Taiwan. USA is the most important scientific research partner of China, in terms of the mutual collaboration strength and unidirectional collaboration. The collaboration relation between Singapore and China is unusually strong when countries' general productivity is taken into account. Singapore has replaced Japan as the 2nd place of China's international collaboration since 2005.

China's international collaboration has mainly carried out with USA and Taiwan in the field of technology innovation, about 30% of China's total patents are jointly applied by inventors from USA and Taiwan. Taiwan owns the strongest mutual collaboration with China when countries' patent output is placed into account, and the following collaboration countries with strong mutual are USA and Singapore. As the countries with high patent yield, for instance, Korea, they hold a large share of China's international collaboration patents though, they are still not the China's most important partner from the perspective of mutual collaboration. It is worthy to mention that some countries with a small amount of patent output have a greater strength of mutual collaboration with China during the past decade, such as Philippines, Malaysia, Thailand, Turkey, Cyprus, Jamaica and United Emirates.

ISC exhibits a continuous raising effect on the citation impact of Chinese papers. Even the countries with a small amount of paper and ISC with China, also exert a

positive influence on the citation impact in Chinese papers; ITC does not always play an active role in the improvement of the citation impact of Chinese patents.

The international collaboration has increased the citation impact of Chinese papers all along the period, with the CPP/FCSm of international collaboration papers higher than the CPP/FCSm of Chinese total papers every year. Unlike the continuous raising effect of international collaboration to the citation impact of Chinese papers, ITC once played an active role in raising the citation impact of Chinese patents before 2007. However, from 2007 to 2008, the figure of CPP/FCSm of international collaboration patents dropped remarkably, and it was lower than the figure in the total patents of China.

In China's ISC, the top 10 countries/regions with high citation impact in international collaboration papers of China have changed every year. Furthermore, there are many developing countries with lower paper output appear in the rankings, such as Indonesia, Vietnam, Philippines, Thailand, and so on. Meanwhile, the countries/regions with more ISC with China, such as USA, Japan, England and so on, also play as active roles in enhancing the citation impact of China's papers. In China's ITC, there's no country/region always play an active role in the improvement of citation impact of China's patents during the period.

The CPP/FCSm of China's international collaboration patents are obviously lower if compared to the international collaboration papers. Most of them are below the world average.

The development of China's international S&T collaboration has been explored through paper and patent analysis; it provides an objective statistic reference to the future policy directions and academic researches. There were limits of the span from 2004 to 2008 in this study. A longer period research with a larger amount of information would be helpful in delineating a more accurate picture. Additionally, analysis of paper and patent data with other informative outputs, such as China's S&T collaboration agreement with other countries (regions) and the international trade, would assist in evaluating the development of China's international S&T collaboration. The statement in above will be added in the future studies.

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