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The trend of concentration in scientific research and technological innovation: A reduction of the predominant role of the U.S. in world research & technology

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ABSTRACT

This study investigates the trend of global concentration in scientific research and technological innovation around the world. It accepts papers and patents as appropriate data for revealing the development and status of science and technology respectively. The performance of these outputs in production and citation impact is taken into consideration in the analysis. The findings suggest that both papers and patents are geographically concentrated on a small number of countries, including the United States, the United Kingdom, Japan, Germany, and France. China has made great progress in paper production and citation impact, and Taiwan and Korea have experienced a rapid growth in patents over the past years. The degree of concentration dramatically decreases when the data from the United States are excluded, indicating the effects of the U.S.'s participation on the concentration. Patents show a higher degree of concentration than papers. With time-varying aspects taken into consideration, the study indicates that the degree of concentration of papers and patents has gradually decreased over time. The concentration of patents has declined more slowly than that of papers. This decrease of the concentration is mainly due to the reduction of the predominant role of the U.S. in world R&D output.

1. Introduction

The political and economic landscape of the world is constantly changing. In 1945 there were 51 member states of the United Nations, and presently the number has increased to 192 countries. The group of major economies has grown from G6 to G8, and then to G8 + 5 in recent decades. It has been announced that the G8 will be superseded by the G20 as the main economic council of wealthy nations. With the growth of world economies, the number of countries enhancing investment in scientific infrastructure and innovation activities has increased accordingly. Many countries have intensive participation in the R&D race and are keen to foster their progress in product of research outputs. Such competition may change the world share of science and ultimately leads the shift of the geographic concentration of scientific research and technological innovation. Certainly it has been shown that the center of gravity of the world system of science and technology shifts with time (Leydesdorff & Zhou, 2005). It is shown that, for example, China demonstrates the world's second largest potential in science and technology. It and other emerging nations like South Korea, Taiwan, Brazil and Turkey are already changing the balance of power as measured by scientific production (Glänzel, Debackere, & Meyer, 2008).

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The production of papers and patents reflects a country's development in scientific research and technological innovation respectively. The performance of papers is related to the status of basic scientific research and the quality of a country's research competence. Patents are often viewed as excellent indicators of technological status, regional or national innovation (Cantwell & Fai, 1999; Zander, 1997), and the capacity for transforming technologies into economically productive output. In studies of geographic concentration of science and technology, papers and patents are often viewed as main data sources and analyzed with respect to different interests in social studies of science.

While there has been an increase of number of countries participating in the R&D market, many researchers indicated that world research output and innovation are concentrated on certain of countries. Sin (2011) analyzed seven LIS Journals from 1980 to 2008 and found that most papers published in high-ranking international journals had been written by authors based in a few nations. Braun et al. also found that in 1980s the production of papers in physics, chemistry, life sciences, engineering, and mathematics was highly concentrated on a small group of countries (Braun, Glanzel, Maczelka, & Schubert, 1994a; Braun, Glanzel, Maczelka, & Schubert, 1994b). King (2004) further pointed out that 31 countries could represent the whole research world in terms of both paper production and citations. Regarding the development of a specific region, Pouris (2009) revealed that science and technology research outputs of Africa are mainly contributed by South Arica and Egypt. Similar findings are obtained in studies focusing on a specific discipline. Golnabi and Mahdieh (2006) indicated that 58.9% of papers and 90.1% of patents in laser technology are from four countries: the United States, Japan, Germany, and China. IFigueira et al. (2007) pointed out that most papers on post-traumatic stress disorder are produced by a small number of countries, although more and more countries have been contributing to studies in this field. With consideration of research population, Kao (2009) demonstrated that authors in operations research were from only a few countries.

In addition to the studies in geographic concentration, research has been conducted to explore the concentration between citations and papers. Guan and Ma (2007) found that citations are concentrated on certain of papers. Similarly, Evans (2008) also indicated that, with regard to online publications, citations are concentrated on only a small number of papers and core journals. Yet Lariviere, Gingras and Archambault (2009) found a decline in the concentration of citations from 1900 to 2007, with consideration of time-varying aspects.

Studies are made to reveal the change of concentration and indicate the trend is toward a gradual dispersal of concentration over the past years (IFigueira et al., 2007; Hullmann, 2007). It seems widely accepted that a growing number of countries participating in science dilutes the concentration of research. However, it is still not clear whether the concentration is shifting in both science and technology, nor how the predominance in R&D changes among countries. Beyond most previous studies, which were inherently limited to certain subject areas, countries, or production of papers, the present study attempts to determine overall trends from both scientific research and technological innovation perspectives.

This study examines the trend of concentration of scientific research and technological innovation. It consolidates data on papers and patents, and illustrates the figures of production and citation impact of papers and patents. Although it is understood that patent concentration is higher than paper concentration, this issue of concentration is seldom addressed in patent analysis. To obtain a comprehensive view of the trend of geographic concentration of R&D output, the present study analyzes the production and citation impact of papers and patents to reveal the concentration and development trends of scientific research and technological innovation. An effort is also made to ascertain which countries have the largest share of papers and patents in the world and how their predominant role changes with time.

2. Methodology

Our study utilizes bibliometric and patentometric methods to explore the concentration of scientific research and technological innovation between 1981 and 2008. It adopts the production and citation impact of papers and patents as indicators of scientific research and technological innovation respectively. Both these measures have been widely used for showing a country's research performance and competitiveness. For example, statistics of paper productivity and impact are very common indicators in university ranking studies (Liu & Cheng, 2005; Marginson, 2009; Quacquarelli, O'Leary, & Ince, 2008), and patent-related measures are largely used by the World Economic Forum, the IMD Business School, and the OECD to evaluate the extents of technological innovations (IMD, 2009; OECD, 2009; WEF, 2009).

Several data sources are compiled into the indicators in the study. Paper-related data are collected from Thomson Reuter's National Science Indicators (NSI), which is developed for investigation of publication output and citation impact at national level. The database contains research articles, notes, and reviews derived from the Web of Science® and have been used in bibliometric studies (Glänzel, Danell, & Persson, 2003). Despite the potential criticism of being a secondary source, it provides us with necessary research-related statistics, including the number of papers and the number of citations. The data of NSI are derived from Web of Science®, which have been widely used in bibliometric studies. Researchers can develop in-depth studies of national-wide scientific trends by using well-established analytical data from over 180 nations around the world. In terms of patents, data are collected from the United States Patent and Trademark Office (USPTO), which provides a wide range of the patents issued since 1976. Despite its focus on U.S.-approved patents and the possibility of a 'home advantage' effect (e.g. Criscuolo, 2006; Li, Lin, Chen, & Roco, 2007; Paci, Sassu, & Usai, 1997), the data source showed a broadest coverage and has been widely adopted in patent analysis (e.g. Gao, Guan, & Rousseau, 2011). Actually this kind of bias is not only present in the USPTO but also in the EPO. It is an inevitable problem that there are some biases, in any appearance, inherent in national or regional patent databases. As the one of the world's primary markets, many patents submitted in other countries are simultaneously submitted for U.S. patents. It is not unreasonable to believe that the USPTO includes most of the world's important inventions, although it does not aggregate patents associated with the same patent family. Regarding these points, this study focuses on U.S. patents granted by the USPTO, rather than includes all patents in the world.

This study investigates the pattern of concentration in science and technology from 1981 to 2008. During these years, a series of political developments altered the global landscape. Many new countries were formed as the result of dissolution of countries or declaration of independence by regions of a country. For example, the dramatic collapse of the Soviet Union in 1991 enabled the independence of Lithuania and the other Baltic states. A significant increase in the number of countries has been observed since then. Our investigation shows that the number of countries with a great share of world research output has consequently grown from 130 in 1989–1993 to 148 in 1994–1998 and 149 in 2004–2008. In order to facilitate close observation of changes and trends across time, we have split the data into five-year periods over the 28 years. The first three years, 1981–1983, is grouped as a period with regard to an assumption that a country's research outputs did not substantially change in the early years of this study.

The numbers of papers/patents and citations are adopted as the main measures in this study. In terms of the number of papers/patents, the measure indicating a country's paper/patent productivity is calculated by the proportion of papers/patents published by that country. In terms of the number of citations of papers/patents indicating a country's paper/patent citation impact, the measure is calculated as the number of cited times of a country's papers/patent from the publication year to the end of 2008. All the above numbers are calculated on annual basis as well as triennial/quinquennial basis. Moreover, each country present in publications receives one credit for its participation.

Several indicators can be used to measure the concentration, such as Herfindahl–Hirschman index, Lorenz curves, Gini coefficient and Brillouin. However, as large scale data are used, it might get similar results no matter which indicators are selected. In the study, Herfindahl–Hirschman Index (HHI) and Gini coefficient are chosen to measure the concentration. HHI was developed by economists to measure market concentration in an industry and is accepted as a screening tool by U.S. federal anti-trust authorities. Gini coefficient is the most common statistical index of diversity or inequality in social sciences (Allison, 1978). Gini coefficient is widely used in econometrics as a standard measure of inter-household inequality in income and wealth (Anand, 1983). Additionally, Gini coefficient also can be viewed as the best known and the most widely used measure of divergence (Shkolnikov, Andreev, & Begun, 2003).

HHI was originally calculated by summing the square of each firm's market share. In the present study, the formula for the calculation is $\sum_{i=1}^{n} S_i^2$, where S_i is the papers/patents share of country i in the world, and n is the number of countries in the investigation.

Gini coefficient, invented by the Italian sociologist Corrado Gini, is a measure of the inequality of a distribution. The value ranges between 0 and 1, indicating full equality (the value is zero) and complete inequality (the value is one). This study uses the Gini coefficient to measure the degree of concentration of a variable in a distribution of its elements. The higher the Gini coefficient presents the greater the concentration. The usual expression of the Gini coefficient is given by the following formula:

$$G = \frac{1}{2\mu N^2} \sum_{i=1}^{N} \sum_{j=1}^{N} |y_i - Y_j|$$

where G is the Gini coefficient, μ the mean value of the distribution, N the sample size, and y_i the number of papers/patents of the ith sample unit.

One criticism on HHI in measuring the concentration of the world's research output is that it does not differentiate the work undertaken by authors from single or multiple countries. A country without any collaborative work can have the same score as a country with massive international collaboration. However, it is still valuable to use the index to investigate the concentration of scientific forces in the world. A research work can be regarded as evidence of the contribution of the authors as well as the participation of their countries in world science, no matter how many researchers worked on it. The share of research outputs, including papers and patents, in the world provides us with an intuitive understanding of a country's forces in R&D activities, while collaboration analysis offers a sharper lens for understanding the main area of research population in the world. Studying the geographical concentration using HHI and Gini coefficient gives us an insight into the configuration of R&D centers in the world.

3. Results

Overall the number of papers and patents increases with time. There were about 0.45 million papers and 73,000 patents completed in 1981, and the numbers have increased to more than 1.13 million and 1,91,000 each in 2008. The growth of paper production increased more than that of patents. In terms of citations, there is a similar bibliometric pattern between papers and patents, yet apparently papers accumulate more citations than patents. The number of citations for papers and patents gradually increased between 1981 and 1995. The number has declined since 1998 for both kinds of literature, reflecting the fact that fewer citations have been accumulated in recent years.

Fig. 1 shows that the number of countries producing patents increased over time, while the number for papers reveals a relatively constant state after 1990. For most of the years about 180 countries' researchers have been published in scientific

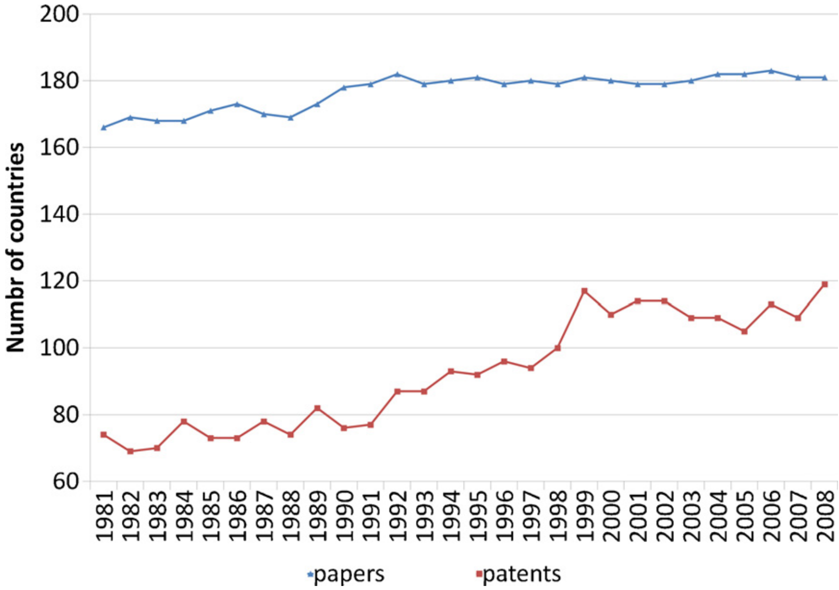

Fig. 1. The number of countries producing papers and patents from 1981 to 2008.

journals; meanwhile, much fewer countries granted patents from USPTO. The differences are attributed to the territoriality of patent law, which places restrictions and requirements on patent applications and grants. Even though geographically patent literature shows a relatively higher concentration than papers, we are not clear about how the differences between these two types of documents vary with time. Therefore, an analysis of the concentration of productivity in and impacts of papers and patents is conducted to examine the changes in the concentration.

3.1. Concentration of scientific research

The results indicate that over the past three decades scientific research has been moderately concentrated in certain number of countries. Although varying with time, the HHI value remains around 0.1–0.2 during 1981–2008, as it is shown in Fig. 2(A). In comparison of the values for each of time periods, a decreasing trend can be found over the past decade. It shows that contemporary scientific research is contributed by more and more countries, rather than being concentrated in a small fraction of nations. In addition, the study shows that the degree of geographic concentration of scientific research is highly related to the participation of the U.S. in the arena. The HHI decreases to less than 0.1 with the exclusion of U.S. papers, indicating that the presence of the United States may foster a high concentration. However, the effects of U.S. participation on the degree of concentration decrease with time. It is found that the HHI declines much more slowly as the U.S. papers are excluded from the population.

The result of Gini coefficient indicates a similar trend to those of HHI. In Fig. 2(B), a decrease of concentration, whether or not including U.S. publications in the data set, is observed as the values of Gini coefficient went down over the past years. The Gini coefficient was 0.91 in 1981–1983 and then diminished to 0.862 in 2004–2008, if all papers are inclued. The result with the exclusion of U.S. papers indicates that the country's influences in the concentration of world's scientific research. The value of Gini coefficient reduced about 0.3 units if the U.S. data are taken out. These results imply a relatively large decline in the domination of the U.S. over the world research output. Further discussion of this point is presented in following paragraphs.

Fig. 2(C) shows that the distribution of citations of papers is more concentrated in specific countries than that of paper outputs. The HHI value reaches almost 0.3 during 1981–1988. The lowest number is in the period of 2001–2008, and it still higher than 0.1. As for the result of the exclusion of U.S. papers from the population, the HHI value is reduced to lower than 0.1 for all the periods. The differences between the HHI for all citations of papers and non-U.S. citations of papers are larger than those between the HHI for all papers and non-U.S. papers, indicating an even more predominant role being played by U.S. research in the concentration of science impact in the world. Yet the effects diminish with time. The study also found the similar result in the analysis by the Gini coefficient in Fig. 2(D). In addition, the trend is consistent with the finding of the decreasing effects of U.S. research on the concentration of research output in the world.

Table 1 displays the top five countries in paper productivity and citation impact, respectively. It shows that over half of the research papers in the world are produced by five countries, in spite of a decrease from 69.4% in 1981–1983 to 50.7% in 2004–2008. Unsurprisingly, the leading countries are the U.S., the U.K., Germany, Japan, and France. That changed in the last period, however – China has made huge progress in its ranking, going from 21st in 1981–1983 to 6th in 1999–2003 to 2nd in 2004–2008. Zooming in the data across time, we found that China is the only country with a continuously growing

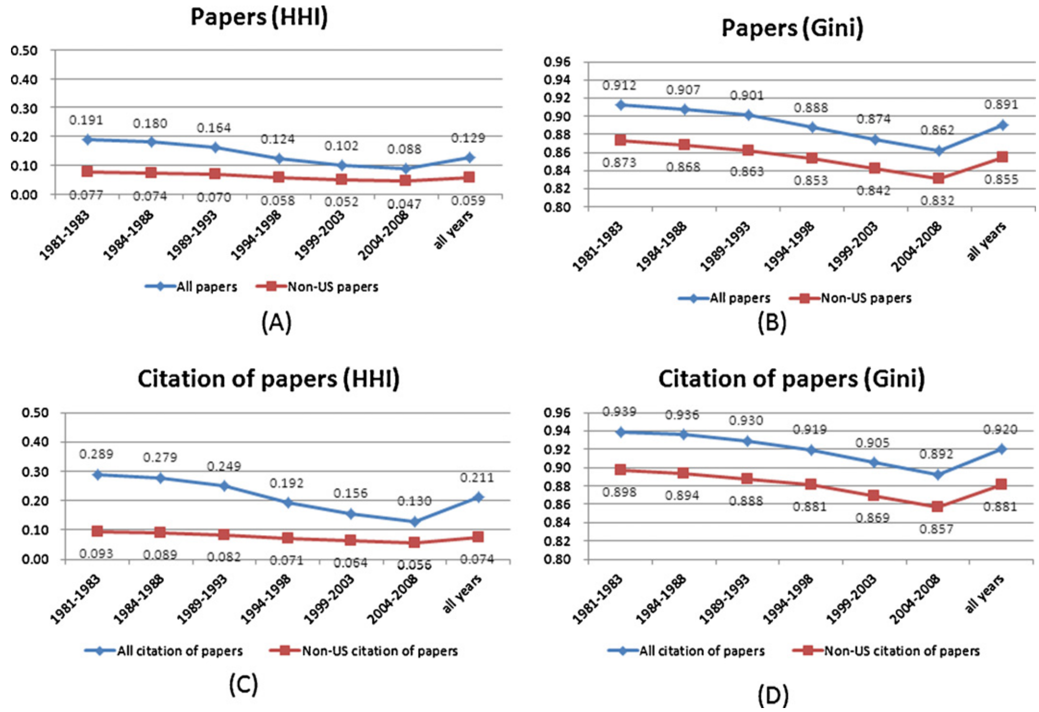

Fig. 2. Concentration in science by (A)HHI based on the number of papers (B) Gini coefficient based on the number of papers (C) HHI for the number of citations of papers (D) Gini coefficient for the number of citations of papers.

share of overall paper output. It had a percentage of 0.6% in the beginning period of 1981–1983 but jumped to 3.7% after about ten years in 1999–2003. The number has reached almost 7% in 2004–2008. By contrast, the U.S. shows a considerable discrepancy in its share of research output, although it remains in the top position over time. As has been mentioned in preceding analysis, the U.S. share of world papers decreased from 40.5% in 1981–1983 to 24.7% in 2004–2008. There is little doubt that the U.S. is the most productive country with a large research population (Soteriades & Falagas, 2005), yet our research gives supportive evidence for China as another giant country which is developing fast and cannot be neglected in world science publications.

In term of citation impact, the U.S., the U.K., Germany, Japan, and France remain in leading positions. These countries placed in the top five in at least one of the investigated periods, as Table 1 illustrates. There is a mild change in the top five ranking – Canada achieved a notable share of citations of papers and ranked at 5th in the beginning periods but was exceeded by France in later years. Although not in the top five list, China has made great progress in citation impact as well as in paper productivity. It ranked at 25th with 0.2% in 1981–1983 but dramatically rose to 7th with 3.8% in citation share. Contrary to this growing trend, the share of U.S. paper citations is decreasing with time. The number reduced from 51.7% in 1981–1983 to 32.3% in 2004–2008. This finding shows that science's impact on the modern world is not entirely determined by the U.S., but also other developing countries, like China.

3.2. Concentration of technological innovation

Compared with scientific papers, the production of patents in the world is much more concentrated on a certain number of countries. As Fig. 3(A) illustrates, the HHI values around 0.3–0.4 are obviously higher than those presented in Fig. 2(A). Even though we excluded the U.S. data from the calculation, the scores still remain generally higher than 0.2 for all the periods. This result shows that there are countries other than the U.S. holding a considerable share of patents in our analysis.

Fig. 3(A) also shows a fluctuant pattern in the HHI value for patents. Although the rate of fluctuation does not reach the statistical significance ($p < 0.05$), the fluctuant phenomenon gradually grew and became popularized. The index fell below 0.4 in 1984–1988 and 1989–1993 but returned to almost the same level in 1994–1998. Another drop appeared in 1999–2003. The HHI value continued to fall in the last period, 2004–2008. The overall trend for HHI value is still one of decline, with a slower rate compared to that for papers.

Generally the patent analysis shows a similar pattern for the non-U.S. and all data after 1994. Nevertheless, there is a different trend before that time. The HHI of the non-U.S. group kept rising in the first three periods; meanwhile, the index fell for the set of all patents. Further observation shows that the figures of these two groups are completely different in 1981–1983 and 1989–1993 – the exclusion of U.S. data caused a noticeable decrease of HHI in the former period, while it

Table 1
Top 5 countries in paper productivity and paper citation impact at different time periods.

	Paper productivity												Paper citation impact											
	1981–1983		1984–1988		1989–1993		1994–1998		1999–2003		2004–2008		1981–1983		1984–1988		1989–1993		1994–1998		1999–2003		2004–2008	
Country	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%
USA	**1**	40.5	**1**	39.0	**1**	36.9	**1**	31.1	**1**	27.3	**1**	24.7	**1**	51.7	**1**	50.8	**1**	47.6	**1**	40.9	**1**	36.1	**1**	32.3
China	21	0.6	17	1.0	13	1.5	11	2.1	6	3.7	**2**	6.8	25	0.2	22	0.4	18	0.6	17	0.9	12	2.0	7	3.8
UK	**2**	8.9	**2**	8.7	**2**	8.2	**2**	7.8	**3**	7.4	**3**	6.6	**2**	9.7	**2**	9.2	**2**	8.7	**2**	8.7	**2**	8.6	**2**	8.0
Germany	**3**	8.1	**3**	7.8	**4**	7.4	**4**	7.1	**4**	7.1	**4**	6.3	**3**	5.8	**3**	5.8	**3**	6.2	**3**	6.9	**3**	7.4	**3**	7.3
Japan	**4**	6.5	**4**	7.1	**3**	7.8	**3**	7.7	**2**	7.7	**5**	6.3	**4**	5.0	**4**	5.4	**4**	5.9	**4**	6.0	**4**	6.2	**4**	5.5
France	**5**	5.4	**5**	5.4	**5**	5.5	**5**	5.4	**5**	5.1	6	4.5	6	4.1	6	4.4	6	4.7	**5**	5.1	**5**	5.0	**5**	4.7
Canada	6	4.5	6	4.9	6	4.8	4	4.0	7	3.6	7	3.7	**5**	4.7	**5**	4.7	**5**	4.9	6	4.5	6	4.1	6	4.1
Top 5		69.4		68.0		65.8		59.1		54.6		50.7		79.9		75.9		73.2		67.6		63.3		57.8

Note. The top five countries of each time period appear in bold. The percentage is calculated as the number of papers/paper citations of a country divided by the number of papers/paper citations of all countries.

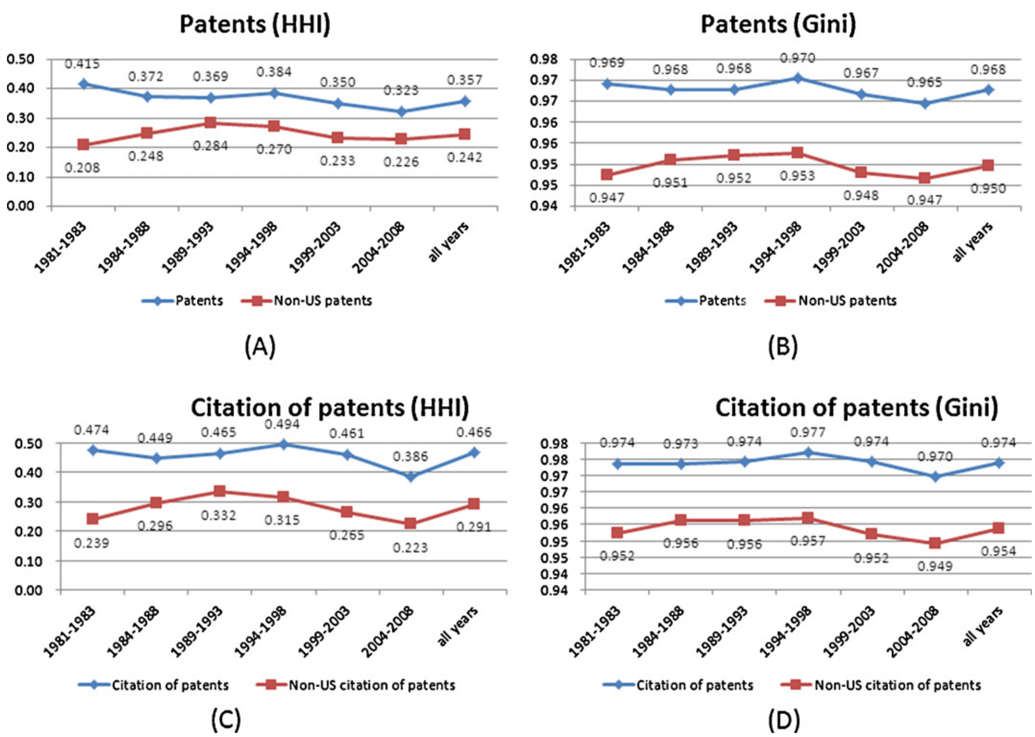

Fig. 3. Concentration in technological Innovation by (A)HHI based on the number of patents (B) Gini coefficient based on the number of patents (C) HHI for the number of citations of patents (D) Gini coefficient for the number of citations of patents.

did not lead to a large change in the later one. The results indicate that the concentration of technological innovation of the world is affected by the U.S. production of patents, and the effects vary with time.

Gini coefficient indicates a similar trend to that of HHI. In Fig. 3(B), Gini coefficient presents the lowest in 2004–2008, implying the decrease of concentration in patents recently. Similarily, the analysis with the exclusion of U.S. patents indicates that the non-U.S. group presented a slightly higher degree of concentration in 1984–1988, 1989–1993, and 1994–1998 than that of the periods afterward.

In Fig. 3(C), the HHI value of patent citation impact is around 0.4–0.5, generally higher than that of patent production. This indicates that the citations of patents are highly concentrated in a small number of countries. The index scores greatly decrease to about 0.2–0.3 if we do not take the share of U.S. based patents into account. The result shows that the high HHI value in patent citation impact is mainly attributable to the influence of the U.S. assignees. Moreover, Fig. 3(C) demonstrates a fluctuation in the concentration of technological innovation across time. Despite the different values between the sets of all patents and non-U.S. based patents, the HHI of patent citations for the both groups has continuously decreased since the middle of 1990s. In terms of the analysis of patent citation of all countries by the Gini coefficient, a similar finding was observed in Fig. 3(D). Gini coefficient of non-U.S. groups showed a slow increase of concentration in the first three periods, yet it presented a decrease of concentration in the last period. It implies that less and less possible for a country to completely dominate the citation impact regarding patents.

Table 2 shows the data of the leading countries in patent production. The top five countries have produced above 85% of patents for each period, much more than the share of 50% in paper-related measures. Across time the proportion of patents produced by the top five countries decreases slightly from 90.9% in 1981–1983 to 86.4% in 2004–2008, while a greater decline in the proportion of papers from 69.4% to 50.7% is observed in the meantime. Apparently the concentration of scientific research declines much faster than that of technological innovation.

The high HHI values in patent related measures are mainly attributed to the high proportion of patents of a few countries. This is particularly related to the large share of patents from the U.S. Over the investigated periods, the U.S. remains at number one in technological innovation. Despite some drops in the proportion, it maintains an over 50% share of patents. In addition the U.S., Japan, as the second largest patent-producing country, also held a certain amount of invention. It owns a share of 14.2% of patents in 1981–1983 and increases the number to 21.1% in 2004–2008. One may notice that the difference between 1st and 2nd in the share of patent production is smaller than that in paper outputs in the same period. Take the last period of 2004–2008 as an example; the difference between the share of patents from the U.S. (52.1%) and Japan (21.1%) is 31%, while that between the U.S. (24.7%) and China (6.8%) is 17.9%.

Compared with the list of top five countries in paper productivity, Table 2 shows that there are a few other countries that have placed in the top five ranking of patent related measures. Taiwan and Korea have shown remarkable performance in

Table 2
Top 5 countries in patent productivity and citation impact at different time periods.

	Patent productivity												Patent citation impact											
	1981–1983		1984–1988		1989–1993		1994–1998		1999–2003		2004–2008		1981–1983		1984–1988		1989–1993		1994–1998		1999–2003		2004–2008	
Country	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%
US	**1**	62.1	**1**	57.2	**1**	56.1	**1**	58.0	**1**	55.1	**1**	52.1	**1**	66.9	**1**	64.1	**1**	65.2	**1**	68.0	**1**	65.5	**1**	59.0
Japan	**2**	14.2	**2**	19.0	**2**	21.8	**2**	20.6	**2**	20.1	**2**	21.1	**2**	14.2	**2**	18.2	**2**	19.3	**2**	17.4	**2**	16.8	**2**	17.7
Germany	**3**	8.5	**3**	8.3	**3**	6.9	**3**	5.5	**3**	5.9	**3**	5.4	**3**	6.4	**3**	5.8	**3**	4.4	**3**	3.3	**3**	3.3	**5**	3.4
Taiwan	18	0.1	12	0.4	9	1.0	6	1.9	**4**	3.4	**4**	4.2	21	0.1	12	0.3	8	0.8	6	1.5	**4**	2.8	**3**	4.6
Korea	32	0.0	23	0.1	13	0.4	8	1.5	6	2.1	**5**	3.6	32	0.0	23	0.1	13	0.3	8	1.0	6	1.7	**4**	4.3
France	**4**	3.1	**4**	3.1	**4**	2.9	**4**	2.3	**5**	2.2	6	1.8	**5**	2.5	**5**	2.3	**4**	2.0	**5**	1.6	7	1.3	7	1.1
Canada	6	1.7	6	1.8	6	1.9	**5**	2.0	7	2.0	7	1.8	6	1.6	6	1.7	6	1.7	**4**	1.7	**5**	2.0	6	1.8
UK	**5**	3.0	**5**	2.8	**5**	2.3	7	1.8	8	1.6	8	1.4	**4**	2.6	**4**	2.3	**5**	1.8	7	1.3	8	1.2	8	1.0
Top5		90.9		90.4		90.0		88.4		86.7		86.4		92.6		92.7		92.7		92.0		90.4		89.0

Note. The top five countries of each time period appear in bold. The percentage is calculated as the number of patents/patent citations of a country divided by the number of patents/patent citations of all countries.

Table 3
Statistical Results of comparing HHI and Gini coefficient between all and non-U.S. paper/patent sets.

	HHI		Gini coefficient	
Data sets	*t* value	*p*-value	*t* value	*p*-value
Top 5 of paper sets	9.813	0.000*	11.316	0.000*
Top 10 of paper sets	7.007	0.001*	6.455	0.000*
Top 30 of paper sets	4.847	0.003*	3.325	0.008*
Top 50 of paper sets	4.460	0.005*	2.498	0.032*
Top 100 of paper sets	4.324	0.005*	2.227	0.050*
Top 5 of paper citation sets	9.897	0.000*	14.995	0.000*
Top 10 of paper citation sets	7.701	0.001*	9.241	0.000*
Top 30 of paper citation sets	5.519	0.002*	3.804	0.003*
Top 50 of paper citation sets	5.155	0.003*	3.032	0.013*
Top 100 of paper citation sets	5.065	0.003*	2.780	0.019*
Top 5 of patent sets	3.551	0.007*	5.656	0.000*
Top 10 of patent sets	6.649	0.000*	10.797	0.000*
Top 30 of patent sets	7.273	0.000*	7.484	0.000*
Top 50 of patent sets	7.227	0.000*	7.134	0.000*
Top 100 of patent sets	7.292	0.000*	6.725	0.000*
Top 5 of patent citation sets	4.384	0.002*	6.236	0.000*
Top 10 of patent citation sets	6.980	0.000*	10.106	0.000*
Top 30 of patent citation sets	7.579	0.000*	7.461	0.000*
Top 50 of patent citation sets	7.584	0.000*	7.478	0.000*
Top 100 of patent citation sets	7.586	0.000*	7.336	0.000*

* $p < 0.05$.

patent productivity in the recent years, whereas China is not in the list for all the periods. It is found that Taiwan and Korea continually increased their share of patents and finally jumped into the top five ranking in the periods of 1999–2003 and 2004–2008, respectively.

Similar findings apply for the measure of patent citation impact, as Table 2 shows. The top five countries produced more than 89% of patent citations for each period, compared with the lowest proportion of 57.8% in paper citation impact. Notwithstanding the relatively slight changes in the total share of the top five countries from 92.6% to 89%, there is a gentle decreasing general trend. As for specific countries, the U.S. and Japan remain the largest holders of patent citations in the study. Both Taiwan and Korea have made great progress in the patent citation impact.

3.3. Comparison between all-paper/patent and non-U.S.-paper/patent sets

The U.S. is determinant in global concentration of scientific research. Table 3 shows the results of comparing HHI and Gini coefficient between all paper/patent and non-U.S. paper/patent sets and indicates that *p* values of all sets are less than 0.05. It indicates that the concentration of all paper/patent and non-U.S. paper/patent sets exist a significant difference. The result implies that U.S. still plays an important role in scientific research and technological innovation, even though the predominant role is decreased. When U.S. is removed from the data set, the degree of concentration of all the other countries has decreased.

As Fig. 4(A) shows, the HHI for the all-paper set is significant higher than that for non-U.S. paper set. Regarding the variation of HHI across time periods, the figure shows that the set including U.S. papers has greater differences than that of non-U.S. papers. For example, the HHI decreases from 0.4 in 1981–1983 to 0.3 in 2004–2008 for the top five countries in the all-paper set, while the value of the index almost remains at the same level of 0.2 for the top five countries in the non-U.S. paper set. Even if the sample is expanded to the top 30, top 50, or top 100 countries, the all-paper set shows a much larger change rate for every time series than the non-U.S. paper set. As Fig. 4(C) shows, the trend of Gini coefficient presents the similar results as HHI.

Moreover, the study also indicates that the HHI and Gini coefficient of top 5 and top 10 countries is relatively high compared with that of top 30, top 50, and top 100. It shows that the global concentration of scientific research can be determined by the top 10 countries rather than by all countries in the world. Many countries have a small share of papers and thus have limited contributions to the change of HHI and Gini coefficient.

Similar findings apply for the concentration of research impact. In Fig. 4(B) and Fig. 4(D), the HHI and Gini coefficient for all citations of papers is relatively higher than that for non-U.S. citations of papers. Substantial variation across time periods for all-citation set is larger than that for non-U.S. citation set.

The HHI for patents is higher than that for papers. In Fig. 5(A), the value for the all-patent set is between 0.3 and 0.5, higher than that for the all-paper set, between 0.1 and 0.4 (see Fig. 4). For non-U.S. patents, the number is between 0.2 and 0.5, larger than that for non-U.S. papers, 0.05–0.2 (see Fig. 4). Yet, like the figures for paper analysis, the results show that the world concentration of patent production can be determined by the top 10 countries. There are remarkable differences of HHI among top 5 and top 10 groups, while top 30, top 50, and top 100 groups remain at similar numbers. Gini coefficient

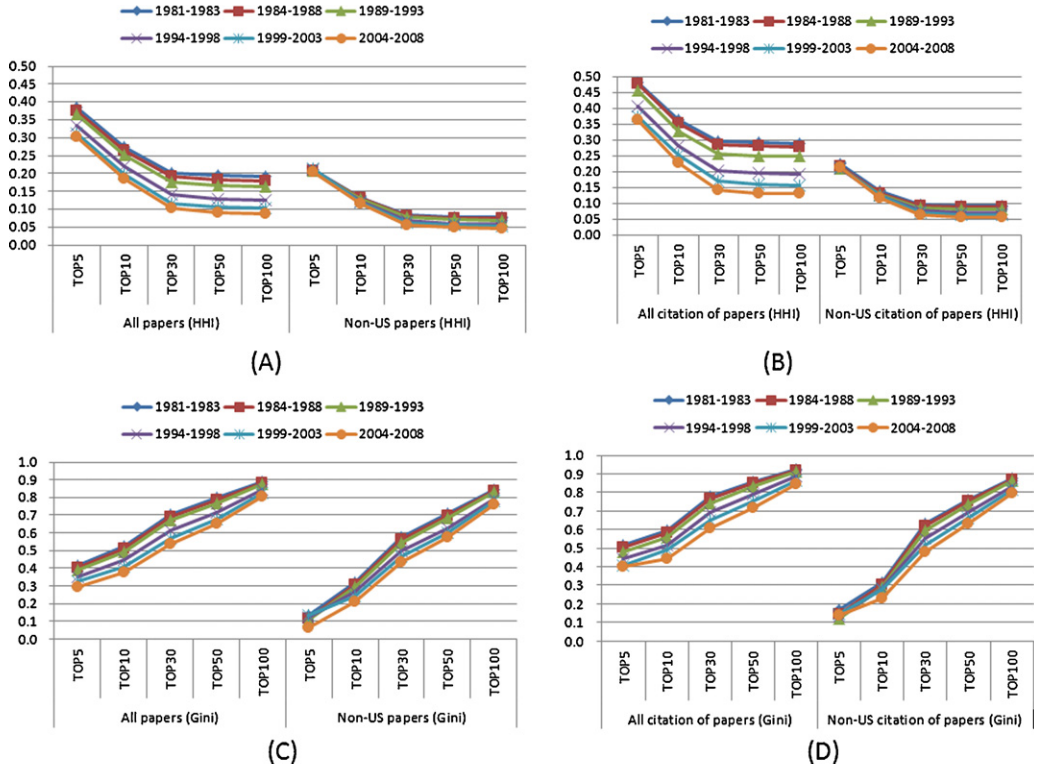

Fig. 4. All-paper and non-U.S.-paper sets, based on (A) HHI for the number of papers (B) HHI for the number of citations of papers (C) Gini coefficient for he number of papers (D) Gini coefficient for the number of citations of papers.

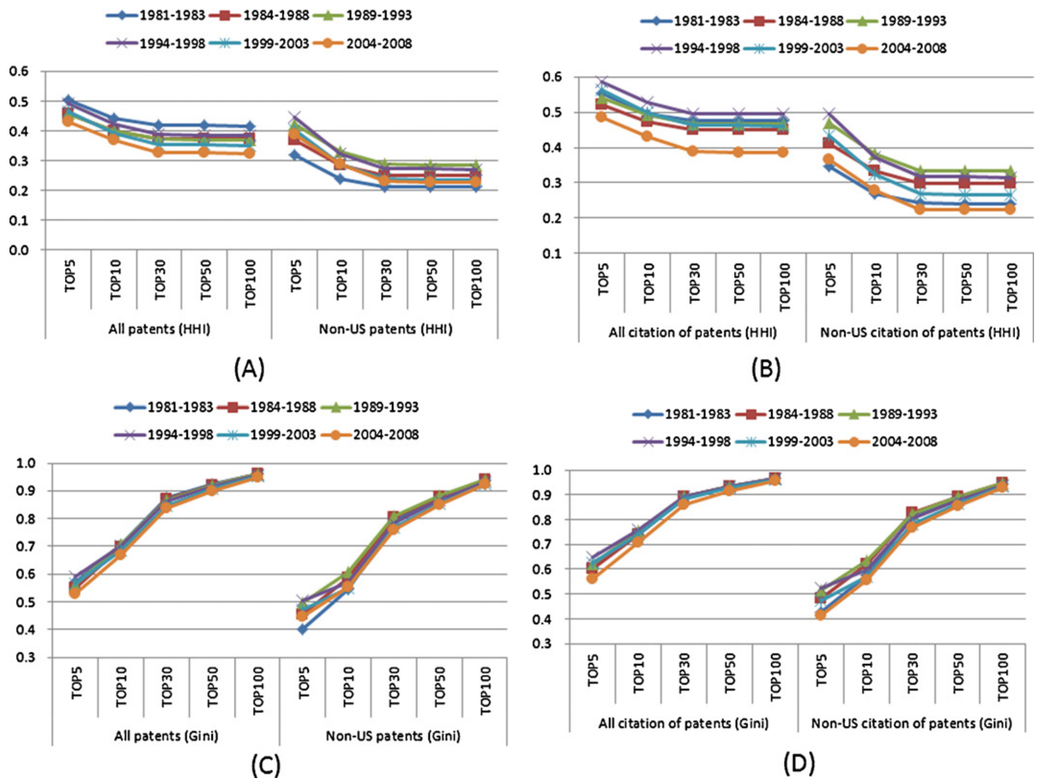

Fig. 5. HHI for all-patent and non-U.S. patent sets, based on (A) the number of patents (B) the number of citations of patents (C) Gini coefficient for he number of patents (D) Gini coefficient for the number of citations of patents.

also presents the similar results in Fig. 5(C). It is understood that most countries hold a limited share of patents and do not have substantial impact on HHI values and Gini coefficient.

Compared with the all-patent set, the non-U.S. set apparently has a lower HHI value and Gini coefficient. Take the period of 1981–1983 as an example; the HHI value decreases from 0.5 to 0.3 if the U.S. data are excluded. This result shows that the global concentration of technological innovation is strongly influenced by the participation of the U.S. The U.S. holds a considerable share of patents and thus affects the value of HHI. The result of Gini coefficient also shows a dominant role of U.S.

Generally HHI values decrease with time. For the all-patent set, the HHI value for period of 1981–1983 is higher than that for period of 2004–2008, for instance. However, there is a different trend for the non-U.S. patent set. The value for the period of 1981–1983 is the lowest among the investigated periods. This is because the U.S. had an overwhelming majority of patents (62%) in this period of time (see Table 2). A large decrease of the HHI is observed if we take out the patents from the U.S. from the data set. The share of patents from outside the U.S. was relatively small and did not have major effects on the HHI value.

There are other countries besides the U.S. that play notable roles in the concentration of technological innovation, nevertheless. As Fig. 5(A) illustrates, no great difference is found between the all-patent and non-U.S. patent sets in the case of the top five countries. For most times, the HHI for the top five countries decreases only about 0.05 after U.S. data are excluded, while the difference exceeds 0.1 and almost reaches 0.2 in the figures for paper sets (see Fig. 4(A)). This indicates there is at least one country that sustains a relatively high HHI in the non-U.S. patent set. Referring to Table 2, we see that Japan has a good share of global patents. It owns 14–18% of patents, greatly higher than the third largest country, Germany, with 3–6%.

Fig. 5(B) and (D) presents the trend of patent citation impact for different groups of countries. It is similar to that of patent production shown in parts (A) and (C) of Fig. 5. Yet a noteworthy observation is that the HHI and Gini coefficient for patent citation impact are higher than that for patent production with consideration of all countries, while a mild difference is found between these figures for the non-U.S. patent set. This implies that the participation of the U.S. affects the concentration of technological innovation.

4. Conclusion

The study finds that the world R&D output is concentrated in a small number of countries from both the scientific research and technological innovation perspectives. The top five countries' shares of papers and patents account for over half of the world's output. The list of leading countries with highest production and citation impact of papers and patents remains the same from 1981 to 2008. It includes developed countries such as the United States, the United Kingdom, Germany, Japan, France and Canada, and countries undergoing rapid industrialization in recent years, such as China, Taiwan, and Korea. This finding is consistent with previous studies (Choung, 1998; Mahmood & Singh, 2003; Youtie, Shapira, & Porter, 2008).

Despite the highly geographic concentration of world papers and patents, a pattern of decline is shown in this study. The sum of the top five countries' share of papers and patents is decreasing across time. Although the U.S. remains in number one throughout the time periods, its share of papers and patents obviously decreases. Rahman and Fukui (2002) found a similar trend in basic science and clinical articles. They showed that the number of papers from the U.S. has declined by approximately 15%, and patents are gradually dropping by about 10%. Contrary to the U.S., other countries are building up their own paper and patent bases. For example, an increasing impact of papers from China and rapid growth of patents from Taiwan and Korea are shown in the results. Jin and Rousseau (2005) also pointed out that Chinese research has experienced a quantitative expansion phase. While China's paper output has increased rapidly, the growth of paper citations has proceeded much slowly. Our study showed that although China more recently ranked in second place in terms of paper production, it does not enter into the top five in terms of paper citations.

Moreover, this study finds that the global concentration of scientific research and technological innovation is affected by the participation of the U.S. The HHI value, Gini coefficient for U.S.-inclusive data is obviously higher than that for non-U.S. papers. It shows that U.S. papers and patents contributes greatly to the increase of HHI values. The degree of concentration drops as U.S. papers and patents are excluded from the data of the study.

Compared with papers, patents show a higher degree of concentration and a lower decrease rate of concentration. The top five countries accounted for more than 86% of patent production, yet held around 50–70% of papers. Several reasons, such as a sustained accumulation of both scientific and technological infrastructure, a mature national market, and a good return on business investment on technologies, are addressed to explain the relatively high concentration of patent production. In citation impact, a similar trend is found. It is shown that the concentration of patent citations is higher than that of paper citations. Both paper and patent data show a decline in concentration of citation impact, and the decrease rate for patents is smaller than that for papers. The top five countries retain a total share of 90% of patent citations for each period of time, while the number decreases from 80% to 60% in paper citations.

In brief, there is apparently a declining trend in geographic concentration of scientific research and technological innovation over the past three decades. This decrease is mainly affected by the reduction of the predominant role of the U.S. in world R&D output. Based on the findings of the current study that regarded all research output of a country as the whole, further research can be made to understand whether and how countries concentrate on few scientific fields. It will give researchers a better understanding of dynamic patterns of research forces in the world.

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References

Allison, P. D. (1978). Measures of inequality. *American Sociological Review*, *43*, 865–880.

Anand, S. (1983). *Inequality and poverty in Malaysia: measurement and decomposition*. New York: Oxford University Press.

Braun, T., Glanzel, W., Maczelka, H., & Schubert, A. (1994a). World science in the eighties. National performances in publication output and citation impact, 1985–1989 versus 1980–1984. Part I. All science fields combined, physics, and chemistry. *Scientometrics*, *29*(3), 299–334.

Braun, T., Glanzel, W., Maczelka, H., & Schubert, A. (1994b). World science in the eighties. National performances in publication output and citation impact, 1985–1989 versus 1980–1984. Part II. Life sciences, enginerring, and mathematics. *Scientometrics*, *31*(1), 3–30.

Cantwell, J., & Fai, F. (1999). Firms as the source of innovation and growth: the evolution of technological competence. *Journal of Evolutionary Economics*, *9*(3), 331–366.

Choung, J. Y. (1998). Patterns of innovation in Korea and Taiwan. *IEEE Transactions on Engineering Management*, *45*(4), 357–365.

Criscuolo, P. (2006). The 'home advantage' effect and patent families: a comparison of OECD triadic patents, the USPTO and the EPO. *Scientometrics*, *66*(1), 23–41.

Evans, J. A. (2008). Electronic publication and the narrowing of science and scholarship. *Science*, *321*(5887), 395–399.

Figueira, I., da Luz, M., Braga, R. J., Cabizuca, M., Coutinho, E., & Mendlowicz, M. V. (2007). The increasing internationalization of mainstream posttraumatic stress disorder research: a bibliometric study. *Journal of Traumatic Stress*, *20*(1), 89–95.

Gao, X., Guan, J., & Rousseau, R. (2011). Mapping collaborative knowledge production in China using patent co-inventorships. *Scientometrics*, *88*, 343–362.

Glänzel, W., Danell, R., & Persson, O. (2003). The decline of Swedish neuroscience: decomposing a bibliometric national science indicator. *Scientometrics*, *57*(2), 197–213.

Glänzel, W., Debackere, K., & Meyer, M. (2008). 'Triad' or 'Tetrad'? On global changes in a dynamic world. *Scientometrics*, *74*(1), 71–88.

Golnabi, H., & Mahdieh, M. H. (2006). Trend of laser research developments in global level. *Optics and Laser Technology*, *38*(2), 122–131.

Guan, J. C., & Ma, N. (2007). A bibliometric study of China's semiconductor literature compared with other major asian countries. *Scientometrics*, *70*(1), 107–124.

Hullmann, A. (2007). Measuring and assessing the development of nanotechnology. *Scientometrics*, *70*(3), 739–758.

Institute for Management Development. (2009). *IMD world competitiveness yearbook 2009*. Lausanne: Author.

Jin, B., & Rousseau, R. (2005). China's quantitative expansion phase: exponential growth but low impact. In P. Ingwersen, & B. Larsen (Eds.), *Proceedings of ISSI 2005* (pp. 362–370). Stockholm, Sweden: Karolinska University Press.

Kao, C. (2009). The authorship and country spread of operation research journals. *Scientometrics*, *78*(3), 397–407.

King, D. A. (2004). The scientific impact of nations. *Nature*, *430*(6997), 311–316.

Lariviere, V., Gingras, Y., & Archambault, E. (2009). The decline in the concentration of citations, 1900–2007. *Journal of the American Society for Information Science and Technology*, *60*(4), 858–862.

Leydesdorff, L., & Zhou, P. (2005). Are the contributions of China and Korea upsetting the world system of science? *Scientometrics*, *63*(3), 617–630.

Li, X., Lin, Y., Chen, H., & Roco, M. C. (2007). Worldwide nanotechnology development: a comparative study of USPTO, EPO, and JPO patents (1976–2004). *Journal of Nanoparticle Research*, *9*(6), 977–1002.

Liu, N. C., & Cheng, Y. (2005). The academic ranking of world universities. *Higher Education in Europe*, *30*(2), 127–136.

Mahmood, I. P., & Singh, J. (2003). Technological dynamism in Asia. *Research Policy*, *32*(6), 1031–1054.

Marginson, S. (2009). Open source knowledge and university rankings. *Thesis Eleven*, *96*(1), 9–39.

Organisation for Economic Co-operation and Development. (2009). *OECD Science, Technology and Industry Scoreboard 2009*. Paris: Author.

Paci, R., Sassu, A., & Usai, S. (1997). International patenting and national technological specialization. *Technovation*, *17*(1), 25–38.

Pouris, A. (2009). The state of science and technology in Africa (2000–2004): a scientometric assessment. *Scientometrics*, *79*(2), 297–309.

Quacquarelli, N., O'Leary, J., & Ince, M. (2008). *Top Universities guide* (2nd edition). London: QS Quacquarelli Symonds Limited.

Rahman, M., & Fukui, T. (2002). A decline in the US share of research articles. *New England Journal of Medicine*, *347*(15), 1211–1212.

Shkolnikov, V. M., Andreev, E. E., & Begun, A. Z. (2003). Gini coefficient as a life table function: computation from discrete data, decomposition of differences and empirical examples. *Demographic Research*, *8*, 305–358.

Sin, S.-C. J. (2011). Longitudinal trends in internationalisation, collaboration types, and citation impact: a bibliometric analysis of seven LIS journals (1980–2008). *Journal of Library and Information Studies*, *9*(1), 27–49.

Soteriades, E. S., & Falagas, M. E. (2005). Comparison of amount of biomedical research originating from the European Union and the United States. *British Medical Journal*, *331*(7510), 192–194.

World Economic Forum. (2009). *The Global Competitiveness Report 2009–2010*. Geneva: Author.

Youtie, J., Shapira, P., & Porter, A. L. (2008). Nanotechnology publications and citations by leading countries and blocs. *Journal of Nanoparticle Research*, *10*(6), 981–986.

Zander, I. (1997). Technological diversification in the multinational corporation - historical evolution and future prospects. *Research Policy*, *26*(2), 209–227.