Journal of Informetrics 6 (2012) 226–236

Contents lists available at SciVerse ScienceDirect

Journal of Informetrics

journal homepage: www.elsevier.com/locate/joi

Globalization of collaborative creativity through cross-border patent activities

Mu-Hsuan Huang[a], Huei-Ru Dong[a], Dar-Zen Chen[b,*]

[a] Department of Library and Information Science, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, 10617 Taipei, Taiwan, ROC

[b] Department of Mechanical Engineering and Institute of Industrial Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, 10617 Taipei, Taiwan, ROC

ARTICLE INFO

Article history:
Received 18 March 2011
Received in revised form
17 September 2011
Accepted 24 October 2011

Keywords:
Patent
Global collaboration
Social network
Collaborative creativity
Patentometrics

ABSTRACT

This study examines global collaborative creativity through patentometrics and social network analysis. Because patents are a direct output of innovative activities, cross-border patents are used to analyze the trend of global collaborative creativity. The results show linear growth of cross-border patents, while numerous inventors have grown exponentially for collaborative creativity. The number of inventors for global collaborative creativity trends have increased more rapidly than the number of patents. The network for global collaborative creativity is denser and shows a growing trend over a five-year interval. Both observed and cosine-normalized numbers of k-cores in global collaborative creativity show a growing trend, while the cosine-normalized k-cores increase slowly compared to the observed one. Similarly, the social network analysis confirms a growing network of global collaborative creativity, which is dense despite its small degree of growth. This study also found that high values of "betweenness" tend to spread from core countries to periphery countries. Collaborative creativity has globalized but remains concentrated in core countries such as the U.S., the UK, France, Germany, and Canada.

1. Introduction

Collaborative creativity has become a trend of continuous demand. Since the evolution of communication and information technology, the arrival of a knowledge-based economy deems creativity a determining factor in the development of a country or the value and profit of a firm. This trend drives us to investigate the trend of globalization or localization of collaborative creativity among countries. The report of Wipro (2007) states that organizations will achieve greater innovation by collaborating with other organizations. Through case study analysis, Wipro proved that collaborative creativity generates more innovations in less time, and the results are often extraordinary. MacCormack, Forbath, Brooks, and Kalaher (2007) found that although the research and development sector of a firm were previously responsible for creativity, that creativity has been generated via networks and collaboration. They claimed collaboration and information exchange as influential in innovation progress. The report (1999) of the Organisation for Economic Co-operation and Development (OECD) indicated that higher competition markets and the rise of science and technology have advanced the progress of innovation. Evans (2008) studied numerous papers and their citations, and found fewer journals and articles were cited, and more of those citations were belong to fewer journals and articles. Huang, Lee, and Chen (2010) found a decreasing concentration of productivity and the impact of papers and patents over time. The concentration of patents is higher than that of papers, and

* Corresponding author. Tel.: +886 2 33662723; fax: +886 2 23692178.
E-mail addresses: mhhuang@ntu.edu.tw (M.-H. Huang), d99126002@ntu.edu.tw (H.-R. Dong), dzchen@ntu.edu.tw (D.-Z. Chen).

1751-1577/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.joi.2011.10.003

the decreasing rate of patents is slower than that of papers. The output ratio of academic research on technology has gradually decreased, influencing worldwide concentration. King (2004) indicated that 31 countries represent global research in terms of both paper production and citations. Current network and collaboration among enterprises is much more important than previously; in an era of globalization, the innovation systems of national governments are mutually dependent on each other.

An approach of extensive use for measuring collaborative creativity between science and technology is to analyze the output. This study regards papers as the output of scientific research and considers patents as the output of technical creativity (Meyer, 2002). Personal, industrial, and national outputs can obtain scientific and technical competitiveness. The co-authorship relationship can also achieve collaboration. Analyzing co-authored publications has been the standard method of measuring collaborative technology and research, and the measurement may appropriately reflect the trend of global research collaboration (Beaver, 2001; Butcher & Jeffrey, 2005; Carayannis & Laget, 2004; Price, 1986; Tijssen, 2004).

Co-authorship presents only partial collaboration (Katz & Martin, 1997; Lundberg, Tomson, Lundkvist, Skar, & Brommels, 2006); however, it still implies the relationships among each co-author. Cooperation includes basic communication and information exchange (Heffner, 1981); therefore, co-authorship is available for collaboration analysis. Based on the Science Citation Index Expanded (SCIE), Leydesdorff and Wagner (2008) investigated global science collaboration and its core in 1990, 2000, and 2005. The network of global science collaboration is growing larger and denser with an increasing number of core countries. However, the number of core countries has decreased after cosine normalization, indicating a closer collaboration within groups. This result suggests a dispersion tendency in global science collaboration; however, the network is focused on a small number of core countries.

Patents are the most appropriate base for analyzing global collaborative creativity. Technical creativity partially results from patents; however, patent statistics is the only measure of formal and publicly verified output of inventive activities (Ma & Lee, 2008). Many scholars have currently adopted patent data for related research on collaborative creativity. Considering the inventors of collaborative creativity, Fleming, Mingo, and Chen (2007) analyzed 35,400 collaborative inventors of utility patents in the United States Patent and Trademark Office (USPTO) between 1997 and 2002, and examined whether broken or cohesive structures generated more collaborative creativity. They found that brokerage networks have generated more innovations; however, these methods block the spreading flows of new ideas and may be used by others. Using patents as objective and appropriate data for analyzing collaborative creativity, Lechevalier, Ikeda, and Nishimura (2007) focused on Japanese patents in robot technology obtained from the Industrial Property Digital Library (IPDL) and Standardized Data ("Seiri-Hyojyunka Data") during 1991–2004. They examined the level of R&D collaboration among inventors of universities, firms, and public research institutions in the robot technology of Japan. The result showed an increase of collaboration between firms and universities, but mainly among firms. The study of Lo (2010) took four indexes, co-assignees, reciprocal citation, patent coupling, and co-patent, to reveal the correlations generated via different citation linkages. The results showed four cluster types, including technological affiliated, technological competitor correlated, commercial collaborated, and technological isolated. Ma, Lee, and Chen (2009) investigated innovative activities of China and its cross-country collaboration with other major industrialized countries and regions through China's patent applications co-filed with other countries or economic entities in the USPTO. An increasing trend of collaborative creativity between China and other major industrialized countries was found, and the rapid technology development of China was predicted based on its swift economic growth. Narin, Breitzman, and Thomas (2005) described the technology value model of CHI Research Inc, presented the result of stock market returns, and considered that applicants and investors should be clearly distinguished.

Schott (1994) mentioned that creation and innovation in modern technology are not separately developed, but include a group of people who collaborate and share ideas. He studied collaborative innovation by observing the patents of multiple inventors issued by the USPTO between 1975 and 1991. The result showed that the number of collaborated patents increased from 40.7% in 1975 to 52.5% in 1991, accounting for more than half of total patents. The increased rate of international collaboration grew faster than that of domestic collaboration, the rate unevenly distributed worldwide, and revealed a completely established structure of collaborative innovation. Guellec and Pottelsberghe de la Potterie (2005) presented three patents based on internationalization indicators to measure knowledge generation. They witnessed an increasing trend toward internationalized technology in all countries. However, large differences existed in the extent of internationalization across countries. Ma and Lee (2008) selected the eight most inventive countries of OECD and two Asian economic entities (South Korea and Taiwan) from 1980 to 2005, and analyzed international collaboration between inventors and assignees across countries in inventive activities via a set of indicator systems. The evaluation result showed that inventive activities have globalized more in the past twenty-five years. Vinkler (1993) used three indicators to characterize the relations between patenting and patented countries in patent output and activity for searching the characteristics of international patenting relations. Nesta and Patel (2005) mentioned the Revealed Technological Advantage (RTA Index and Specialization Index), which are important indicators of characterizing country developmental levels by fields. Based on the utility patent data from the USPTO, Chen and Guan (2010) emphasized collaborative patents from 16 major countries during 1975–2006. According to the theory of small world network, they explored the relationship between composition and innovation with country level. The result showed that a small world network does benefit creativity, but only in certain limited fields. Breschi and Lissoni (2005) also analyzed social network to gain the maps of social relationships between inventors, and measured the social proximity between cited and citing patents.

In a related analysis of the linkage between patents and papers, Narin and Breitzman (1995) adopted Lotka's patent law to investigate inventive productivity. Narin, Hamilton, and Olivastro (1997) traced the rapid growth linkage of citations between U.S. patents and scientific papers. Narin and Olivastro (1998) compared the linkage between patents and papers in the European Patent Office (EPO) and the USPTO. In the field of biotechnology, McMillan, Narin, and Deeds (2000) analyzed the linkage between patents and papers to understand further the critical role of public science innovation in the field of biotechnology. Huang (2009) also focused on the interaction between science and technology of Giant Magnetoresistance (GMR) from both scientific literatures and patent documents.

As mentioned above, several scholars have attempted to elaborate the internationalization or localization of collaborative creativity among countries based on patent information. The effects of globalization can be easily found, in contrast, scientific research and technical creativity are special topics. With a focus on global technology innovation, the present study explores long-term cross-country collaborative creativity through abundant patent information, and detects whether collaborative creativity is becoming internationalized. This work analyzes changes in the number of global collaborative patents and inventors in the USPTO during 1990–2009, and applies social network analysis. Because the U.S. has a large proportion of USPTO-grated patents, a cosine normalization is conducted to reduce the impact made by maximal and minimal values. The changes in the number of k-core countries and the trend presented in the social network analysis due to cosine normalization are compared and contrasted. The changes in distribution of k-core countries are discussed to identify the degree of globalization. The centrality among major countries is analyzed to determine the trend of each dominant country during a twenty-year period.

2. Methodology

This study adopts patentometrics, social network analysis, and the patterns of global collaborative creativity to discuss the globalization trend in patent collaborations. Patentometrics takes a large quantity of patents and objective quantitative numbers to observe the collaboration performance of study objects. Total technical creativity only partially results from patents; however, patent statistics is the only formal and public verified output of inventive activities and co-authorship only presents partial collaboration. Therefore, this study uses patents to present collaborative creativity, which cannot be analyzed in the restrictions of this study. Social network analysis is an analytic technique extensively used in sociology. In this study, countries with collaborative relationships are taken as “nodes,” and the collaborative creativity between them is called the “link.” Various indicators used in social network analysis measure the degree and trend of the connection of global collaboration. Global patents seem to be concentrated in a small number of countries (Golnabi & Mahdieh, 2006; Huang, Lee, & Chen, 2010). Global collaborative patents are subject to normalization to avoid the bias of disparate data. The new network of global collaboration is compared with the original one after removing extremely low values of several analysis links.

2.1. Data collection

The patent data are utility patents from the USPTO during 1990–2009. The patent is considered a cross border patent with international collaboration, which means the patent belongs to more than one inventor, and its inventors come from more than one country. The patent amount per country is calculated by integer counting; each country is only counted once, no matter how many countries an individual patent belongs to. Taking five years as an interval, this study analyzes the changes and trends of globalization in collaborative creativity. Patent analysis is typically based on the country of inventors or assignees, but the inventor and the assignee do not always come from the same country. The collaborative relationships of inventors across different countries fail to discover if the analysis is based on the country of assignees. Therefore, this study analyzes data by the country of the inventor in global collaborative creativity.

A higher ratio of patents in the U.S. and Canada compared to the patents of other countries in the USPTO may cause “home advantage” (Criscuolo, 2006). However, the study of Huang et al. (2010) found that the concentration trend resulted in similar academic papers and technology patents, even when excluding U.S. papers and patents. Collaborative creativity is analyzed by the statistic of cosine normalization, which can effectively reduce the effect of extreme value and the country advantage of the patent system the owner belongs to.

Table 1 shows 2,749,651 utility patents in the USPTO during 1990–2009. Patents totaling 2,734,268 (99.44%) are produced by 6,458,897 inventors, excluding the patents without country information of the inventor. Cross-border patents with cross-country collaboration are further selected for analysis. A total of 114,059 cross-border utility patents (4.17%) produced by

Table 1
The number of patents/cross-border patents/inventors between 1990 and 2009.

	(1) No. of all patents	(2) Patents with country name	(3) No. of inventors	(4) Cross-border patents	(5) No. of inventors in cross-border patents	(6) % of cross-border patents	(7) % of inventors in cross-border patents
1990–1994	487,024	484,557	1,018,556	11,208	38,876	2.31%	3.82%
1995–1999	632,197	624,278	1,419,056	22,780	86,144	3.65%	6.07%
2000–2004	827,343	824,582	1,982,082	37,684	149,654	4.57%	7.55%
2005–2009	803,087	800,851	2,039,203	42,387	178,276	5.29%	8.74%
1990–2009	2,749,651	2,734,268	6,458,897	114,059	452,950	4.17%	7.01%

452,950 inventors is taken as the research sample. 4.17% of cross-border patents is relatively low, compared with 23.3% international collaboration research papers in the study of Leydesdorff and Wagner (2008). This difference results from various characteristics of patents and research papers (Golnabi & Mahdieh, 2006; Huang et al., 2010). The number of cross-border patents of a two-decade study increased from 11,208 to 42,387, a growth of 3.78 times. The percentage share of cross-border patents also increased from 2.31% to 5.29%, 2.29 times. An obvious growth of cross-border patents is shown from an amount of 11,208 to 42,387, even though the percentage is low. Cross-border patents are still the minority of USPTO-granted patents, while continuous growth and increasing proportion deserve more attention.

2.2. Indicators

This study takes the quantitative approach and social network analysis. The indicators are shown as follows.

2.3. k-Core

Seidman (1983) proposed that identifying high and low cohesion by a minimum degree criterion can find the structure of components. The k-core is a maximal sub-graph, in which each point is at least adjacent to k of other nodes; all the nodes within the k-core have a greater degree than or equal to k (Scott, 2000).

2.4. Betweenness centrality

Freeman (1978) advocated the use of betweenness to present the concept of point centrality. The concept is a measure of node centrality in a network. In other words, the number of shortest paths from all vertices to others passes through that node. Betweenness centrality is a more useful measure of the load placed on a given node in the network, and the node toward the network is more important than the node for individual connectivity. Betweenness centrality of a node v is given as follows:

$$BC(v) = \sum_{\substack{u,\, w \in v \\ u \neq w \neq v}} \frac{\sigma_{uw}(v)}{\sigma_{uw}}$$

where $\sigma_{uw}(v)$ denotes the total number of shortest paths between u and w that pass through node v and σ_{uw} denotes the total number of shortest paths between u and w.

3. Results

3.1. The trend in global collaborative creativity

Fig. 1 visualizes the growth in global collaborative creativity based on the data provided in Table 1. Both the numbers of patents and inventors have increased, however, the growth of inventors is faster than the growth of patents. The number of patents shows a linear growth from an amount of 11,208 in the interval of 1990–1994 to a sum of 42,387 in the interval of 2005–2009. In contrast, the number of inventors shows an exponential growth from an amount of 38,876 in the interval of

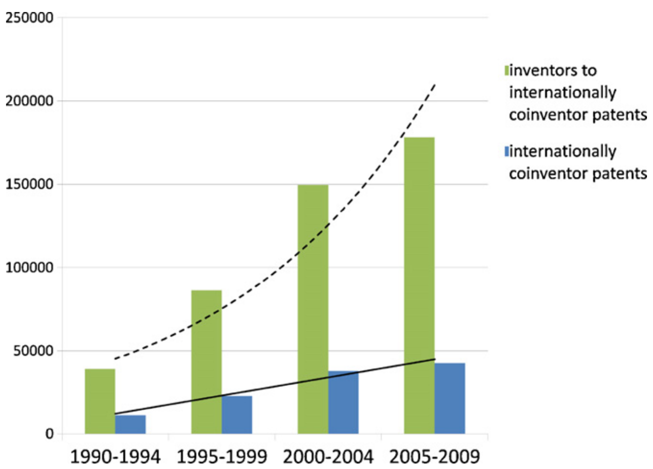

Fig. 1. Global collaborative patents and their inventors.

Table 2
Social network analysis of the global science network.

Network statistic	1990–1994	1995–1999	2000–2004	2005–2009	1990–2009
Number of nodes	116	137	144	143	191
Number of links	964	1488	1838	2090	2968
Size k-core component	12	16	20	22	25
Number of nodes in the first k-core	13	26	26	31	13
Network density	1.83	2.78	4.32	4.97	7.33
Average degree	7.23	7.99	8.93	10.29	8.18
Average distance	2.15	2.07	2.05	2.04	2.07
Diameter	2	3	3	4	3
Graph betweeness	0.55	0.56	0.45	0.45	0.44
Average clustering coefficient	215.10	427.43	730.07	709.76	1858.03

1990–1994 to a sum of 178,276 in the interval of 2005–2009. The average number of inventors per patent has also increased, from 3.47 in 1990–1994 to 4.21 in 2005–2009.

Patents in global collaborative creativity have grown linearly, while inventors have grown exponentially. Technology development, the enhanced concept of copyrights, business competition, and the evolution of communication technology are factors causing the expansion of patents and inventors. The exponential growth of inventors indicates numerous people devoted to collaborative inventions. The result of the growing trend might be affected by the evolution of communication technology, professional specialization, and a larger scale of research collaboration.

This study further examines the 114,059 cross-border patents by social network analysis. The number of nodes in the twenty-year study accounts for 191 countries. From the data of Table 2, there are 116 countries of the number of nodes among 1990–1994, and an amount of 137 countries in 1995–1999, which have increased by 21 countries. The growth rate of countries has decreased, with 144 countries in 2000–2004 and 143 countries during 2005–2009. In the earlier period, an increasing number of countries participated in collaborative creativity. In the later period, the growth rate slowly changed, and one country withdrew from international collaboration. Across four five-year intervals, the number of links signifies the relationships of co-inventors from two different countries. The result shows a rising tendency which slows afterwards, along with the number of nodes. The analysis result is not consistent with the rapid expansion of links in global scientific research in the study of Leydesdorff and Wagner (2008).

The k-core component value signifies each country at least adjacent to k of other countries in the k-core group, which increased from 12 to 22 in two decades. Network density also increased, indicating that countries have been closer in the network with the increasing number of countries in the k-core. The average degree slowly climbed from 7.23 to 10.29, indicating a significant expansion of influential spread across the network. This study calculates the average degree by the rising tendency, according to the findings of Leydesdorff and Wagner (2008). However, the rising tendency is not as high as their result of scientific collaboration (the number is from 22.4 to 48.6). The difference shows that the increasing effect of collaborative patents is still much lower than that of collaborative research papers. The average distance declined from 2.15 to 2.04, whereas the diameter climbed from 2 to 4, indicating a smaller distance and greater connection in the network.

Graph betweenness measures the extent that a country logically lies on the center of other countries among the global creativity network. The result shows the gradually decreasing extent of graph betweenness of these countries, and the decreasing number of countries in core positions over time. The result exhibits a wide variety of choices that are not limited to several specific countries when inventors of a country search for collaboration partners from foreign countries. The average clustering coefficient measures the intermediary role a country plays, which is central to the network. The result shows the decreased value of the average clustering coefficient with time, although it once slightly increased and decreased again afterward. This result demonstrates that the range of partners of countries in the global creativity network is not limited to several specific countries.

3.2. Effects of normalization

This study conducts cosine normalization to decrease the patterns of U.S. and Canada dominated in the network. Fig. 2 presents k-core changes with diverse cosine normalization. The original k-core reaches from 12 to 22 with a linear growth in four five-year intervals. After cosine normalization, the k-core value has increased from 10 to 15 with slight growth. The finding is not consistent with the study result of Leydesdorff and Wagner (2008), which found a decreasing tendency after cosine normalization in global scientific research. The difference indicates a slowly increasing number of composing countries in the k-cores after cosine normalization.

Table 3 shows the analytic result of social network after cosine normalization. According to Table 2, the number of nodes remains the same; however, the number of links has decreased. In addition, the links have reduced in recent years. The value of the k-core component has increased from 10 to 14, a growth tendency that is lower than the original k-core component. The degree of network density of each interval has been similar and slightly decreasing after normalization, indicating that the density of core countries in the network of global collaboration remains nearly the same, only with a slight decrease. The average degree has gradually climbed from 6.58 to 7.29, which is lower than the original statistics. This result indicates a broader spread of influence across the network. The results of average distance, diameter, and graph betweenness are similar

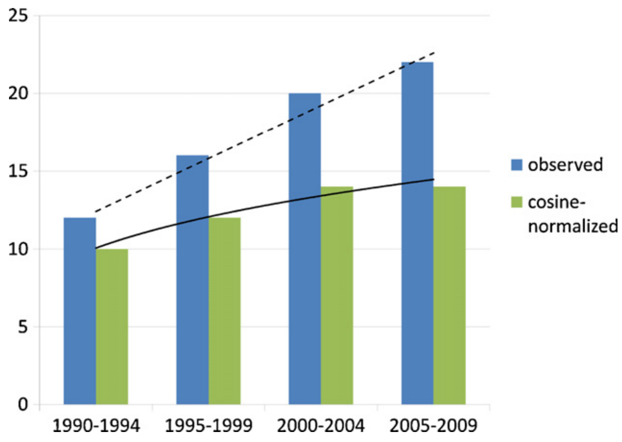

Fig. 2. Changes in k-cores before and after cosine normalization.

to the original statistics, indicating a smaller distance and greater connection among these countries. Because the major countries of global collaborative creativity have lost their positions in the core of collaborative partners, many countries are more diverse. The values of the average clustering coefficient are also close to the original statistics; the tendency decreased at the beginning, slightly rose, and decreased afterwards. This social network analysis with normalization shows that the collaboration between countries is not limited to a small number of countries but is diversified.

To further understand the countries in the k-core component and the related factors of linguistic and geographic elements, Figs. 3 and 4 show the countries in the first k-core component (yellow background) and the second k-core component (blue background) during the changes caused by cosine normalization. Fig. 3 presents the original structure of k-cores. When the research analyzed continents, North American countries such as the U.S. and Canada, remained in the first k-core for twenty years. The U.S. would certainly qualify as a k-core country since the research data are obtained from the USPTO. Canada has a geographic advantage to become a k-core country. Europe is the continent with the most countries in the k-core. This high ratio indicates flourishing globalization in Europe. Asia ranks as the second continent with the most k-core countries, followed by Europe. The increasing k-core countries of Asia and Europe seem to follow a similar pattern; however, Asia has a higher range of increase. The periphery countries of Oceania, South America, Africa, and Australia also remained in the first k-core. South Africa was in second k-core during 1990–1994, and dropped out afterward; the remaining countries slowly became k-core countries, revealing a globalization trend. (For interpretation of the references to color in this paragraph, the reader is referred to the web version of the article.)

More countries have attended the first k-core. During 1990–1994, there were 13 countries in the first k-core: North American countries such as the U.S. and Canada; European countries such as Denmark, Belgium, the Netherlands, the UK, Finland, France, Germany, Switzerland, and Sweden; and Asia-Pacific countries such as Japan and Australia. The countries above have remained in the k-core for twenty years. Countries of the second k-core include European countries such as Austria, Italy, Norway, Spain, and Ireland; Asian countries such as Singapore and Israel; and South Africa. During 1995–1999, there were 26 countries in the first k-core. The new existing countries were European countries (Austria, Italy, Norway, Spain, Russia, and Ireland) and Asian countries (Singapore, Israel, China, Taiwan, India, South Korea, and Malaysia). The only countries in the second k-core were Poland and Brazil. Comparing the k-cores in the first two intervals, the new countries of the first k-core in 1995–1999 were almost same as the ones in the second k-core in 1990–1994.

From a geographical perspective, the k-core is spreading from Central Europe to Southern Europe, Eastern Europe, and West Asia, or from Japan to Southeast Asia. During 2000–2004, there were 26 countries in the first k-core. Brazil of South America was a new participant in the first k-core, whereas Ireland of Europe dropped from the first k-core. During the span

Table 3
Social network analysis of the global science network (normalization).

Network statistic	1990–1994	1995–1999	2000–2004	2005–2009	1990–2009
Number of nodes	116	137	144	143	165
Number of links	878	1208	1342	1480	1584
Size k-core component	10	12	14	14	15
Number of nodes in the first k-core	16	17	17	16	16
Network density	0.0023	0.0019	0.0018	0.0019	0.0011
Average degree	6.58	6.48	6.52	7.29	4.37
Average distance	2.15	2.07	2.05	2.04	2.07
Diameter	2	3	3	4	3
Graph betweeness	0.55	0.56	0.45	0.45	0.44
Average clustering coefficient	0.74	0.72	0.73	0.72	0.66

continent	Language*	1990-1994	1995-1999	2000-2004	2005-2009
North America	English	**Canada**	**Canada**	**Canada**	**Canada**
	English	**United States**	**United States**	**United States**	**United States**
Europe	Danish	**Denmark**	**Denmark**	**Denmark**	**Denmark**
	Dutch	**Belgium**	**Belgium**	**Belgium**	**Belgium**
	Dutch	**Netherlands**	**Netherlands**	**Netherlands**	**Netherlands**
	English	**United Kingdom**	**United Kingdom**	**United Kingdom**	**United Kingdom**
	Finnish	**Finland**	**Finland**	**Finland**	**Finland**
	French	**France**	**France**	**France**	**France**
	German	**Germany**	**Germany**	**Germany**	**Germany**
	German	**Switzerland**	**Switzerland**	**Switzerland**	**Switzerland**
	Swedish	**Sweden**	**Sweden**	**Sweden**	**Sweden**
	German	Austria	**Austria**	**Austria**	**Austria**
	Italian	Italy	**Italy**	**Italy**	**Italy**
	Norwegian	Norway	**Norway**	**Norway**	**Norway**
	Spanish	Spain	**Spain**	**Spain**	**Spain**
	Russian	Russia	**Russia**	**Russia**	**Russia**
	English	Ireland	**Ireland**	Ireland	**Ireland**
	Polish	Poland	Poland	Poland	**Poland**
	Czech	Czech Republic	Czech Republic	Czech Republic	**Czech Republic**
	Hungarian	Hungary	Hungary	Hungary	Hungary
	Russian	Ukraine	Ukraine	Ukraine	Ukraine
Asia	Japanese	**Japan**	**Japan**	**Japan**	**Japan**
	English	Singapore	**Singapore**	**Singapore**	**Singapore**
	Hebrew	Israel	**Israel**	**Israel**	**Israel**
	Chinese	China	**China**	**China**	**China**
	Chinese	Taiwan	**Taiwan**	**Taiwan**	**Taiwan**
	English	India	**India**	**India**	**India**
	Korean	South Korea	**South Korea**	**South Korea**	**South Korea**
	Malay	Malaysia	**Malaysia**	**Malaysia**	**Malaysia**
	Turkish	Turkey	Turkey	Turkey	**Turkey**
Oceania	English	**Australia**	**Australia**	**Australia**	**Australia**
	English	New Zealand	New Zealand	New Zealand	**New Zealand**
South America	Portuguese	Brazil	Brazil	**Brazil**	**Brazil**
Africa	English	South Africa	South Africa	South Africa	South Africa

* Main official language
** Countries in the first k-core are in boldfaced type and yellow background; countries in the second k-core are in blue letters and blue background

Fig. 3. Countries in k-cores between 1990 and 2009.

of 2005–2009, there were 31 countries in the first k-core. Twenty-six countries were in the first k-core in 2000–2004, and Ireland also rejoined the group. The other new countries of the first k-core were Poland, the Czech Republic, Turkey, and New Zealand. This reveals that the k-core is spreading to the periphery.

When the research is analyzed by languages, 34 countries entered the first and second k-core in the twenty-year study. Nine countries adopted English as the official language; three of them made German the official language. Dutch, Russian, and Chinese were used by two countries, and the remaining countries have their own official languages. The language disparity indicates that global collaboration does not correlate with language, but with geographical distance.

According to the data of Fig. 4, the first k-core after cosine normalization remains mostly the same, centering on North America, Europe, Japan, and Australia. During 1990–1994, there were 16 countries in the first k-core: North American countries such as the U.S. and Canada; Asian-Pacific countries such as Japan and Australia; and European countries such as Denmark, Belgium, the Netherlands, the UK, France, Austria, Germany, Switzerland, Italy, Sweden, Norway, and Ireland. Except for Norway and Ireland, the other 14 countries have remained in the k-core for twenty years. During the periods of 1995–2009 and 2000–2004, the k-core countries constituted the same 17 countries. Compared to the countries of 1990–1994, Finland and Spain were new participants in the k-core, while Ireland dropped from the k-core. During 2005–2009, Norway dropped from the k-core, leaving 16 countries in the k-core. The results indicate a slight change in k-core countries. According to the geographic perspective, most countries are from North America and Central Europe. Normalization reveals the degree of concentration of participating countries in global collaborative creativity.

The second k-core shows a rising trend in numbers after cosine normalization, which differs from the previous trend of diminution. During 1990–1994, there were six countries in the second k-core: Finland, Spain, Israel, Brazil, Mexico, and

continent	Language*	1990-1994	1995-1999	2000-2004	2005-2009
North America	English	**Canada**	**Canada**	**Canada**	**Canada**
	English	**United States**	**United States**	**United States**	**United States**
Europe	Danish	**Denmark**	**Denmark**	**Denmark**	**Denmark**
	Dutch	**Belgium**	**Belgium**	**Belgium**	**Belgium**
	Dutch	**Netherlands**	**Netherlands**	**Netherlands**	**Netherlands**
	English	**United Kingdom**	**United Kingdom**	**United Kingdom**	**United Kingdom**
	French	**France**	**France**	**France**	**France**
	German	**Austria**	**Austria**	**Austria**	**Austria**
	German	**Germany**	**Germany**	**Germany**	**Germany**
	German	**Switzerland**	**Switzerland**	**Switzerland**	**Switzerland**
	Italian	**Italy**	**Italy**	**Italy**	**Italy**
	Swedish	**Sweden**	**Sweden**	**Sweden**	**Sweden**
	Finnish	Finland	**Finland**	**Finland**	**Finland**
	Spanish	Spain	**Spain**	**Spain**	**Spain**
	Norwegian	**Norway**	**Norway**	**Norway**	Norway
	Russian	Russia	Russia	Russia	Russia
	English	**Ireland**	Ireland	Ireland	Ireland
	Polish	Poland	Poland	Poland	Poland
	Czech	Czech Republic	Czech Republic	Czech Republic	Czech Republic
	Greek	Greece	Greece	Greece	Greece
	Hungarian	Hungary	Hungary	Hungary	Hungary
Asia	Japanese	**Japan**	**Japan**	**Japan**	**Japan**
	Hebrew	Israel	Israel	Israel	Israel
	Thai	Thailand	Thailand	Thailand	Thailand
	Arabic	United Arab Emirates	United Arab Emirates	United Arab Emirates	United Arab Emirates
	Chinese	China	China	China	China
	English	Singapore	Singapore	Singapore	Singapore
	English	India	India	India	India
	Korean	South Korea	South Korea	South Korea	South Korea
	Malay	Malaysia	Malaysia	Malaysia	Malaysia
	Turkish	Turkey	Turkey	Turkey	Turkey
Oceania	English	**Australia**	**Australia**	**Australia**	**Australia**
	English	New Zealand	New Zealand	New Zealand	New Zealand
South America	Portuguese	Brazil	Brazil	Brazil	Brazil
	Spanish	Mexico	Mexico	Mexico	Mexico
Africa	English	South Africa	South Africa	South Africa	South Africa

* Main official language

** Countries in the first k-core are in boldfaced type and yellow background; countries in the second k-core are in blue letters and blue background

Fig. 4. Countries in k-cores between 1990 and 2009 (after normalization).

South Africa. During 1995–1999, there were six countries in the second k-core, such as Russia, Ireland, Hungary, Poland, Israel, and Thailand. During 2000–2004, Russia was the only country in the second k-core. In the period of 2005–2009, there were 18 countries in the second k-core: European countries such as Norway, Russia, Ireland, Poland, Czech Republic, and Greece; Asian countries such as Israel, Thailand, the United Arab Emirates, China, Singapore, India, South Korea, Malaysia, and Turkey; and New Zealand of Oceania, Brazil in South America, and South Africa in Africa. Comparing the countries in the first and second k-cores, second k-core countries are in the periphery areas and form a group in which Asian and Oceania countries have more influence than European countries do.

Figs. 3 and 4 show an increasing number of countries in the first k-core before cosine normalization, showing a growth tendency. In contrast, there are fewer countries in the second k-core, which shows a decreasing tendency. However, countries in the second k-core typically join the first k-core in later periods. The data after cosine normalization shown in Fig. 4 indicates a smaller number of countries in the first k-core than that shown in Fig. 3. The first k-core countries are more concentrative, showing a slower growth rate; the second k-core countries also have a growth tendency. Not all countries have moved to the first k-core but have formed as a group. Of the countries forming the first k-core before cosine normalization, 13 have remained in the first k-core in all four periods, including Canada, the U.S., Denmark, Belgium, the Netherlands, the UK, Finland, France, Germany, Switzerland, Sweden, Japan, and Australia. After cosine normalization, 14 countries have remained in the first k-core in all four periods, including Canada, the U.S., Denmark, Belgium, the Netherlands, the UK, France, Austria, Germany, Switzerland, Italy, Sweden, Japan, and Australia. Among the analysis, Finland dropped from the k-core in all four periods after cosine normalization, whereas Austria and Italy were included in the k-core in all four periods.

Table 4
Rank order by the percentage of betweenness centrality, cosine ≧ 0.01.

1990–1994		1995–1999		2000–2004		2005–2009	
U.S.	57.18	U.S.	58.18	U.S.	48.04	U.S.	46.24
France	14.65	France	7.37	France	11.41	UK	9.55
UK	12.59	Germany	6.33	UK	10.73	Germany	8.22
Germany	8.51	UK	5.90	Germany	10.32	Canada	7.92
Canada	4.80	Japan	5.77	Canada	6.12	France	5.82
Switzerland	3.64	Russia	5.14	Switzerland	5.79	Switzerland	4.29
Japan	2.82	Canada	3.87	Japan	3.88	Belgium	4.07
Austria	2.22	Sweden	3.73	Israel	2.64	Japan	3.66
Mexico	1.86	Switzerland	2.46	Sweden	2.49	India	3.09
Vatican	1.74	Spain	2.31	Singapore	2.12	Russia	2.81

The result exhibits that Austria and Italy have a closer connection with the k-core after less significant links are removed from normalization.

The network of global collaborative creativity has grown larger and denser; the core of the network structure has also grown after cosine normalization. In the study of global science network by Leydesdorff and Wagner (2008), the result showed a larger and denser network growth. However, the global science network structure has not grown after cosine normalization. Global collaborative creativity with a rising trend differs from the global science network, in which geographical proximity seems more influential than language does.

Compared with the global science network of Leydesdorff and Wagner, Japan, Australia and Canada were in this network but not in the set of science k-core. The increasing influence of Asian countries seems limited to Japan and Australia; and Eastern Europe does not carry as great an affect as the Pacific does. The result of global science network by Leydesdorff and Wagner and the network of global collaborative creativity of the current study are very similar. This result corresponds with the comparison of Huang et al. (2010), in which academic study and patent technology remain concentrative in several main countries. The concentration of patents is higher than the concentration of paper, and the decreasing rate of patent concentration is slower than the paper concentration is. Among the alternant position of Scandinavian countries in the global science network, Sweden and Denmark remain stable, while Finland and Norway are more marginal in the network. However, Finland is still in the creativity network. Poland and Russia provide a major difference, applied in the k-core science network, but not in the patent network. The two network systems can differ, but may have been increasingly similar due to globalization and increasing knowledge-based innovations.

Table 4 shows the percentage rank of betweenness centrality in the four periods. Betweenness centrality measures the extent to which a particular country lies between other countries. A country with higher betweenness centrality has greater influence on other countries (Freeman, 1978). According to Table 4, the percentage of U.S. betweenness centrality has been much larger than that of other countries, and the percentage has remained the highest over twenty years. Although the U.S. has retained a central position, its extent of centrality is not as high as formerly. This trend indicates that core countries of collaborative creativity have gradually spread out, contrary to the findings of the global science network by Leydesdorff and Wagner (2008), in which the U.S. lost its central position. The study result shows that the U.S. has retained the central position despite its gradual decrease of centrality.

Seven countries have remained in the top ten of measured betweenness centrality in two decades: the U.S., France, the UK, Germany, Canada, Switzerland, and Japan. The betweenness centrality value of the above countries has slightly increased and declined afterward, except for Canada, whose value have slightly declined and risen afterward. This result shows a tendency of decreasing betweenness centrality in core countries of collaborative creativity, except for Canada. France held the second highest betweenness centrality in the first fifteen years, but ended in fifth place in 2005–2009, revealing that its central position had greatly decreased. In betweenness centrality performance of Asian countries, Singapore and India ranked within the top ten during 2000–2004 and 2005–2009. This ranking indicates that Asian countries hold the newly important role. A higher percentage of international collaboration between small and newly emerging countries might be factors causing this result. Different industries will also cause various patenting activities in different fields. For example, international patents dominant in the U.S. and Sweden are in the field of ABB, (Bergek & Bruzelius, 2010). However, compared to the result of betweenness centrality shown in the study of global science network, the density of global collaborative creativity drops after normalization, but the number remains higher than that of the global science network.

4. Conclusion and discussion

This study analyzes the trend of global collaborative creativity and takes the USPTO-issued patents during 1990–2009 to study the growth of patents and their inventors. Cosine normalization is conducted to reduce the home advantage of the U.S. in the USPTO database. Social network analysis is utilized to show the trend of global collaborative creativity. The following presents the conclusions of this paper.

4.1. Continuous growth of global collaborative creativity

Cross-border patents and their inventors have continuously grown due to global collaborative creativity. The patent share of cross-border patents is not high; however, it has rapidly grown from 2.31% to 5.29%. The low percentage rate does not readily reveal the growth, but the total number of patents has strikingly increased from ten thousand to more than 40,000. The growth of patent inventors has even extended faster and shown exponential growth, with an average number of 3.47 inventors per patent increasing to 4.21 persons.

4.2. The larger and denser network of collaborative creativity

The network of collaborative creativity has not only grown larger, but also denser. The result of social network analysis indicates that the number of participant countries in collaborative creativity has grown from 116 to 143 countries, and the number of links has grown from 964 to 2090. All indicators of social network analysis show a closer connection among network countries. A country can choose various collaboration partners, and some core countries have lost their central positions because of the widening options of cooperative partners.

4.3. The network of collaborative creativity has become larger and denser but gradually reaches a saturated state after normalization

Due to the effect of cosine normalization, the significance of countries with home advantage has reduced. The network of collaborative creativity continues to grow and become denser until reaches a saturation state. The result of social network analysis is dense but slightly spread out, suggesting that inventors of one country have a wider variety of choices for a collaboration partner from other foreign countries, unlike the decreasing tendency in the number of k-core countries after cosine normalization, shown in the global science network by Leydesdorff and Wagner (2008). The result of this study indicates a growth tendency in the number of core countries in global collaborative creativity. The analysis result of scientific papers and the network of collaborative creativity of the two studies mentioned above are similar to the study result by Huang et al. (2010). The concentration of patents is higher than the concentration of papers, and the decreasing rate of patent concentration is slower than that of paper concentration.

4.4. Global collaborative creativity is affected more by geographical distance than by language

The distribution of k-core countries correlates more strongly with geographical distance than with language. Based on the changes and distribution of the first and second k-cores, global collaborative creativity is effected more by geographical distance than by language. In other words, k-core countries exhibit a closer collaboration with neighbor countries, but not with countries in the same language system.

4.5. Global collaborative creativity spreads out to periphery countries, which causes second k-core countries to form a group after cosine normalization

Global collaborative creativity tends to spread out to periphery countries. First k-core countries are concentrated in North America, Central Europe, Northern Europe, Japan, and Australia, showing a tendency of spreading out to neighbor periphery countries. Countries in the second k-core have slowly moved to the first k-core. A slight change exists in the composition of k-core countries after cosine normalization. First k-core countries have remained mostly the same, but have not spread out to neighbor periphery countries. Second k-core countries have increased in number and formed a group.

4.6. Participant countries in global collaborative creativity are concentrated in Europe and North America; as the effect of European and North American countries decreases, the effect of Asian countries increases

Participant countries in global collaborative creativity are mainly concentrated in Europe and North America. However, the decreasing effect of European and North American countries is countered by the increasing influence of Asian countries. Although the value of betweenness centrality in the U.S. has declined, the percentage that remains under 50%, still rules a significant portion. This analysis result corresponds with the study of Huang et al. (2010), who found that the ratio of academic study and technology output in the U.S. has gradually declined and influenced the concentration condition. The effect of Canada has increased, whereas the effect of European countries has decreased. Among Asia-Pacific countries, Singapore and India both exhibit an increasing influence. The countries of Asia and Oceania have had greater influence than European countries have. These behaviors indicate an increasing number of countries engaged in collaboration with periphery countries, even if the countries of Europe and North America retain dominant positions during this span.

This study analyzes the globalized trend of collaborative creativity by the network of global collaborative patents, which might include analytic limitations. The network of collaborative patents is one factor, which might cause the common tendency of globalization. Co-authorship and patents are both types of collaborative creativity outputs, resulting in a great difference of patent output in various fields. The finding of this research suggests the tendency of k-core countries in the network of global collaborative patents.

References

Beaver, D. B. (2001). Reflections on scientific collaboration (and its study): Past, present, and future. *Scientometrics*, *52*(3), 365–377.

Bergek, A., & Bruzelius, M. (2010). Are patents with multiple inventors from different countries a good indicator of international R&D collaboration? The case of ABB. *Research Policy*, *39*, 1321–1334.

Breschi, S., & Lissoni, F. (2005). Knowledge networks from patent data. In *Handbook of quantitative science and technology research* (pp. 613–643).

Butcher, J., & Jeffrey, P. (2005). The use of bibliometric indicators to explore industry–academia collaboration trends over time in the field of membrane use for water treatment. *Technovation*, *25*(11), 1273–1280.

Carayannis, E. G., & Laget, P. (2004). Transatlantic innovation infrastructure networks: Public–private, EU-US R&D partnerships. *R and D Management*, *34*(1), 17–31.

Chen, Z., & Guan, J. (2010). The impact of small world on innovation: An empirical study of 16 countries. *Journal of Informetrics*, *4*(1), 97–106.

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.

Fleming, L., Mingo, S., & Chen, D. (2007). Collaborative brokerage, generative creativity, and creative success. *Administrative Science Quarterly*, *52*(3), 443–475.

Freeman, L. C. (1978). Centrality in social networks conceptual clarification. *Social Networks*, *1*(3), 215–239.

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

Guellec, D., & Pottelsberghe de la Potterie, B. (2005). Measuring the internationalisation of the generation of knowledge. In *Handbook of quantitative science and technology research* (pp. 645–662).

Heffner, A. (1981). Funded research, multiple authorship, and subauthorship collaboration in four disciplines. *Scientometrics*, *3*(1), 5–12.

Huang, M. H., Lee, W. Y., & Chen, D. Z. (2010). On the concentration of productivity and impact in science and technology. In R. Sabherwal, & S. Soloon (Eds.), *2010 IEEE international conference on management of innovation & technology (ICMIT 2010)* (pp. 203–208). Singapore: IEEE.

Huang, Y. H. (2009). An investigation of the interaction between science and technology from literatures of giant magnetoresistance. *Journal of Library and Information Studies*, *7*(1–2), 53–76.

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy*, *26*(1), 1–18.

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

Lechevalier, S., Ikeda, Y., & Nishimura, J. (2007). Investigating collaborative R&D using patent data: The case study of robot technology in Japan. *Discussion Paper Series A*, no. 498.

Leydesdorff, L., & Wagner, C. S. (2008). International collaboration in science and the formation of a core group. *Journal of Informetrics*, *2*(4), 317–325.

Lo, S. C. S. (2010). A comparative study of linkage indexes: Co-assignee, reciprocal citation, patent coupling and co-patent. *Journal of Library and Information Studies*, *8*(1), 11–27.

Lundberg, J., Tomson, G., Lundkvist, I., Skar, J., & Brommels, M. (2006). Collaboration uncovered: Exploring the adequacy of measuring university–industry collaboration through co-authorship and funding. *Scientometrics*, *69*(3), 575–589.

Ma, Z., & Lee, Y. (2008). Patent application and technological collaboration in inventive activities: 1980–2005. *Technovation*, *28*(6), 379–390.

Ma, Z., Lee, Y., & Chen, C. P. (2009). Booming or emerging? China's technological capability and international collaboration in patent activities. *Technological Forecasting and Social Change*, *76*(6), 787–796.

MacCormack, A., Forbath, T., Brooks, P., & Kalaher, P. (2007). *Innovation through global collaboration: A new source of competitive advantage*. Citeseer.

McMillan, G. S., Narin, F., & Deeds, D. L. (2000). An analysis of the critical role of public science in innovation: the case of biotechnology. *Research Policy*, *29*(1), 1–8.

Meyer, M. (2002). Tracing knowledge flows in innovation systems. *Scientometrics*, *54*(2), 193–212.

Narin, F., & Breitzman, A. (1995). Inventive productivity. *Research Policy*, *24*(4), 507–519.

Narin, F., & Olivastro, D. (1998). Linkage between patents and papers: An interim EPO/US comparison. *Scientometrics*, *41*(1-2), 51–59.

Narin, F., Breitzman, A., & Thomas, P. (2005). Using patent citation indicators to manage a stock portfolio. *Handbook of Quantitative Science and Technology Research*, 553–568.

Narin, F., Hamilton, K. S., & Olivastro, D. (1997). The increasing linkage between U.S. technology and public science. *Research Policy*, *26*(3), 317–330.

Nesta, L., & Patel, P. (2005). National patterns of technology accumulation: Use of patent statistics. In *Handbook of Quantitative Science and Technology Research* (pp. 531–551).

OECD. (1999). *Managing national innovation system*. Paris: OECD.

Price, D. J. D. S. (1986). *Little science, big science and beyond*. New York: Columbia University Press.

Schott, T. (1994). Collaboration in the invention of technology: Globalization, regions, and centers. *Social Science Research*, *23*(1), 23–56.

Scott, J. (2000). *Social network analysis: A handbook* (2nd ed.). London: SAGE Publications.

Seidman, S. B. (1983). Network structure and minimum degree. *Social Networks*, *5*(3), 269–287.

Tijssen, R. J. W. (2004). Is the commercialisation of scientific research affecting the production of public knowledge? Global trends in the output of corporate research articles. *Research Policy*, *33*(5), 709–733.

Vinkler, P. (1993). Percentage patent representation (PPR) bilateral patent balance (BPB) and patent dominancy (PD) indicators characterizing international patenting relations. *Scientometrics*, *27*(1), 97–103.

Wipro. (2007). *Innovation and the power of collaboration*. Wipro Council For Industry Research. Retrieved from http://www.wipro.com/resource-center/wipro-council-for-industry-research/pdf/innovation_and_the_power_of_collaboration.pdf